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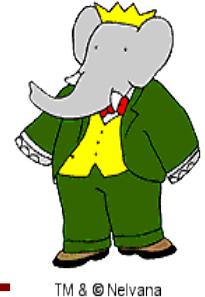
CP violation in $B^0 \rightarrow D^{(*)+}D^{*-}$ decays

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Fermi National Accelerator Laboratory
October 7, 2008



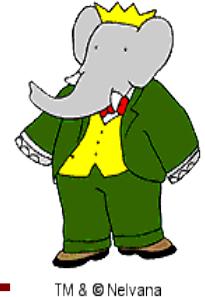
Outline



-
- Introduction to CP violation
 - The *BABAR* experiment
 - Selecting signal events
 - Transversity analysis for CP -odd fraction
 - Time-dependent CP measurements
 - Conclusion

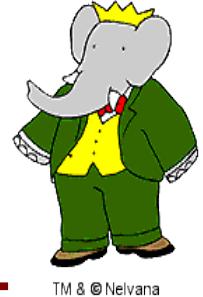


CP violation



- In 1964, Christensen, Cronin, Fitch, and Turlay observed *CP* violation in the decays of K_L^0 to two pions. Cronin and Fitch received the Nobel prize.
- In 1967, Sakharov included *CP* violation as one of the important conditions to produce the matter/anti-matter asymmetry we observe in the universe.
- *CP* violation is an important phenomenon arising from electro-weak symmetry breaking.

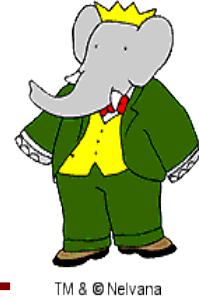
The Cabibbo-Kobayashi-Maskawa quark mixing matrix



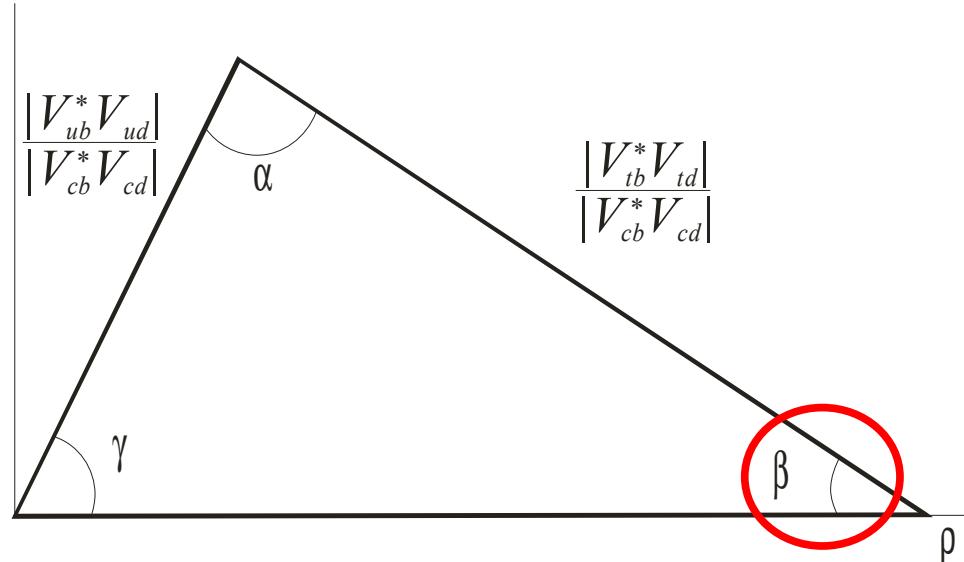
- The Cabibbo-Kobayashi-Maskawa (V_{CKM}) quark mixing matrix is a 3×3 , unitary matrix for the weak interactions connecting u type and d type quarks.
- CP violation is explained by an irreducible complex phase in the matrix.

$$\begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} = \begin{pmatrix} 1 - \frac{\lambda^2}{2} & \lambda & A\lambda^3(\rho - \boxed{i\eta}) \\ -\lambda & 1 - \frac{\lambda^2}{2} & A\lambda^2 \\ A\lambda^3(1 - \rho - \boxed{i\eta}) & -A\lambda^2 & 1 \end{pmatrix} + \mathcal{O}(\lambda^4)$$

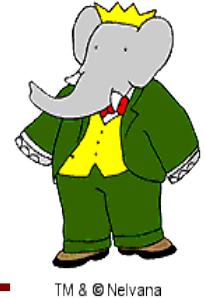
The Unitarity Triangle



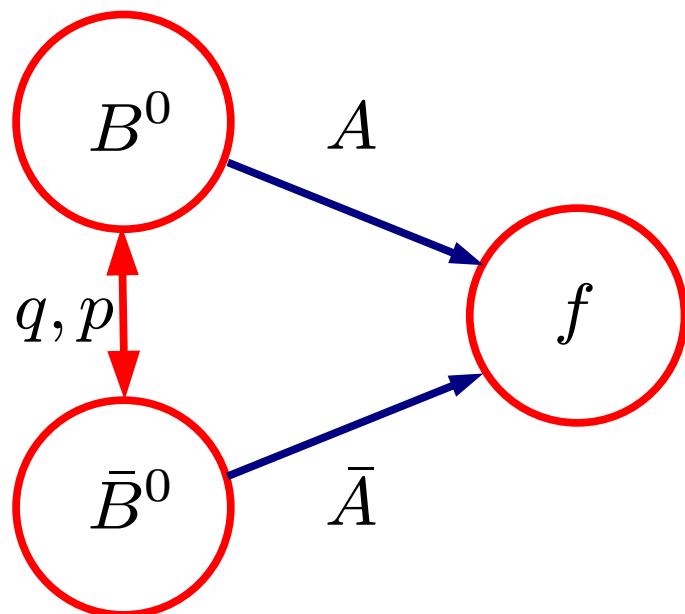
- The unitarity of V_{CKM} provides the relationship
$$V_{ub}^* V_{ud} + V_{cb}^* V_{cd} + V_{tb}^* V_{td} = 0$$
- Measuring β is a principle physics goal ⁿ of the B factories.
- Ultimately over-constraining the CKM triangle could show weaknesses in the SM.



Time-dependent CP violation



$$a_{CP}(t) = \frac{\Gamma(\bar{B}^0(t) \rightarrow f) - \Gamma(B^0(t) \rightarrow f)}{\Gamma(\bar{B}^0(t) \rightarrow f) + \Gamma(B^0(t) \rightarrow f)} = S \sin \Delta m t - C \cos \Delta m t$$

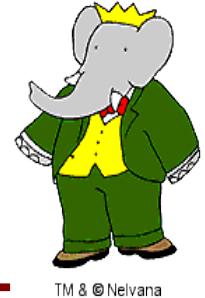


$$\lambda = \frac{q}{p} \frac{\bar{A}}{A}$$

$$S = \frac{2\text{Im}\lambda}{1 + |\lambda|^2} \propto \sin 2\beta$$

$$C = \frac{1 - |\lambda|^2}{1 + |\lambda|^2} \approx 0$$

$\sin 2\beta$ from “golden” $B^0 \rightarrow (c\bar{c})K^0$ decays

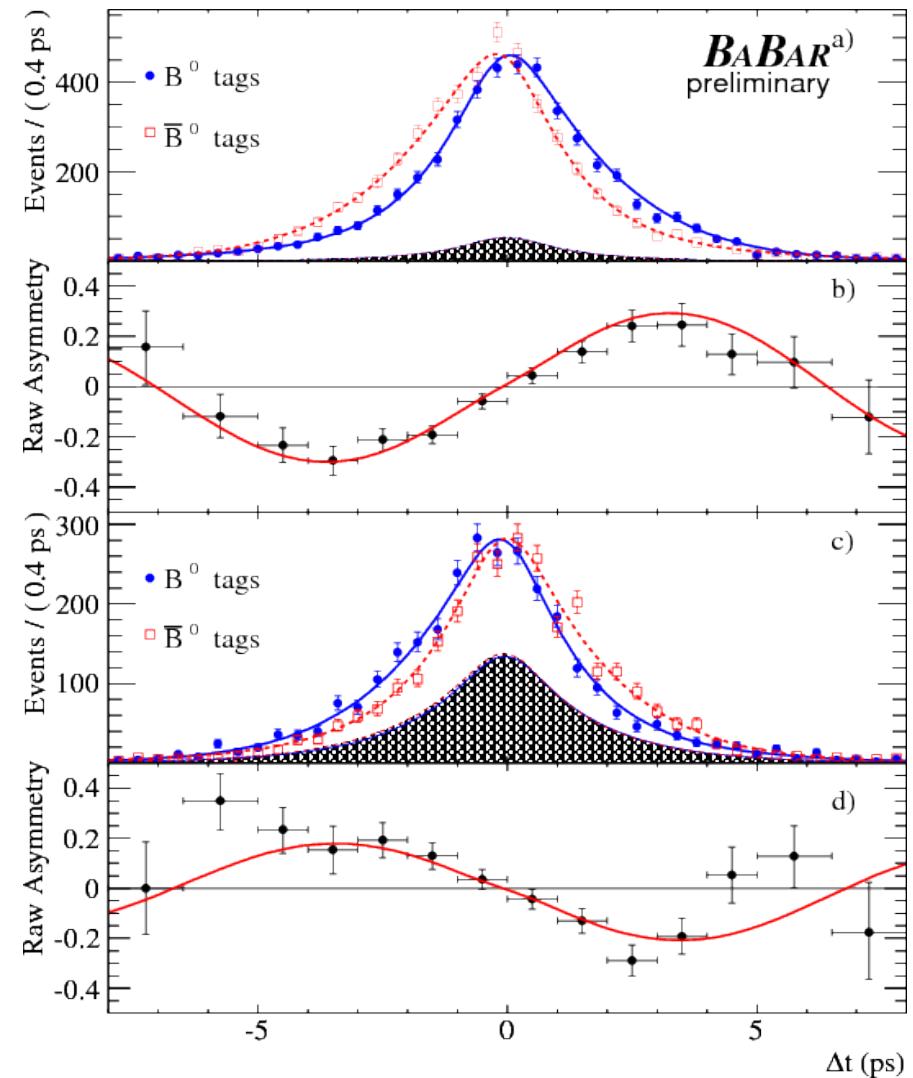


- Theoretically clean.
- Large branching fraction
- High signal purity

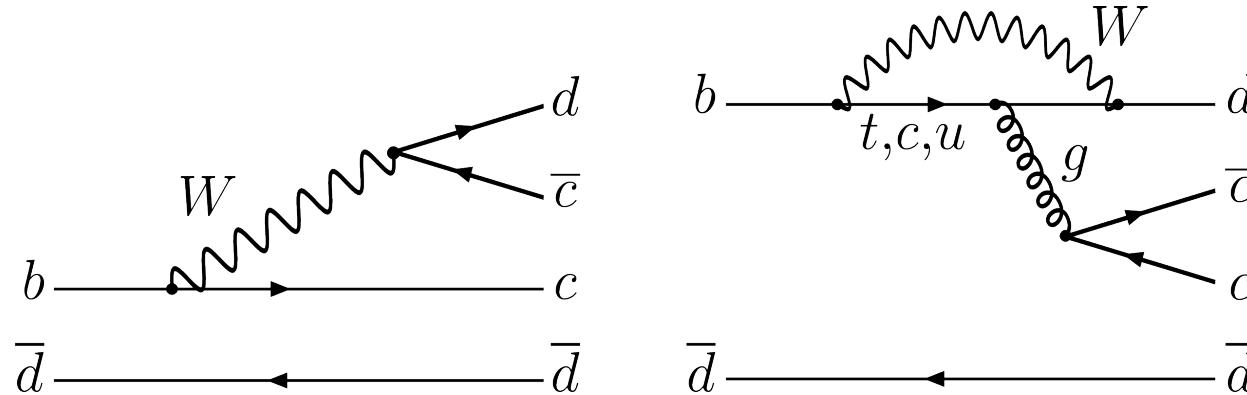
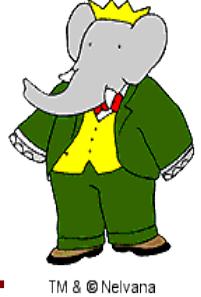
$$S = 0.691 \pm 0.029 \pm 0.014$$

$$C = 0.026 \pm 0.020 \pm 0.016$$

arXiv:0808.1903 [hep-ex]

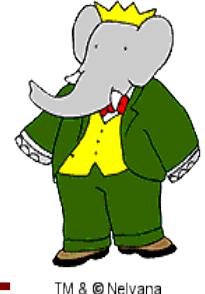


$\sin 2\beta$ from $B^0 \rightarrow D^{(*)+}D^{*-}$ decays



- At the tree level CP asymmetry is expected to be $-\sin 2\beta$.
- Contributions from the penguin amplitude pollutes a direct $\sin 2\beta$ measurement.
 - Contribution expected to be small 2-5 %. PRD 61 014010
 - Larger deviations could signal new physics contributions in the loop. PLB 395 241, arXiv:0805:4601, PRD 77 036004

CP dilution of the $B^0 \rightarrow D^{*+}D^{*-}$ decays



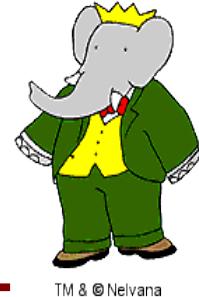
- The contribution from different orbital angular momentum partial wave amplitudes for this decay dilutes the $\sin 2\beta$ measurement.

$$S_{\text{eff}} = (1 - 2R_{\perp})S$$

- Fortunately the angular distribution of the D^* decay products can measure R_{\perp} and yield an undiluted S .

PRD 43 2193

Experimental status



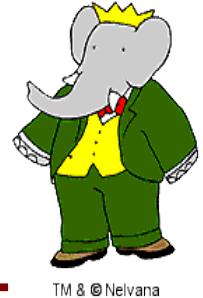
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- The Belle Collaboration has observed large direct CP violation in the $B^0 \rightarrow D^+D^-$ channel.

$$\begin{array}{lll} D^+D^- & 535 \text{ M } B\bar{B} & S = -1.13 \pm 0.37 \pm 0.09 \\ & \text{PRL 98 221802} & C = -0.91 \pm 0.23 \pm 0.06 \end{array}$$

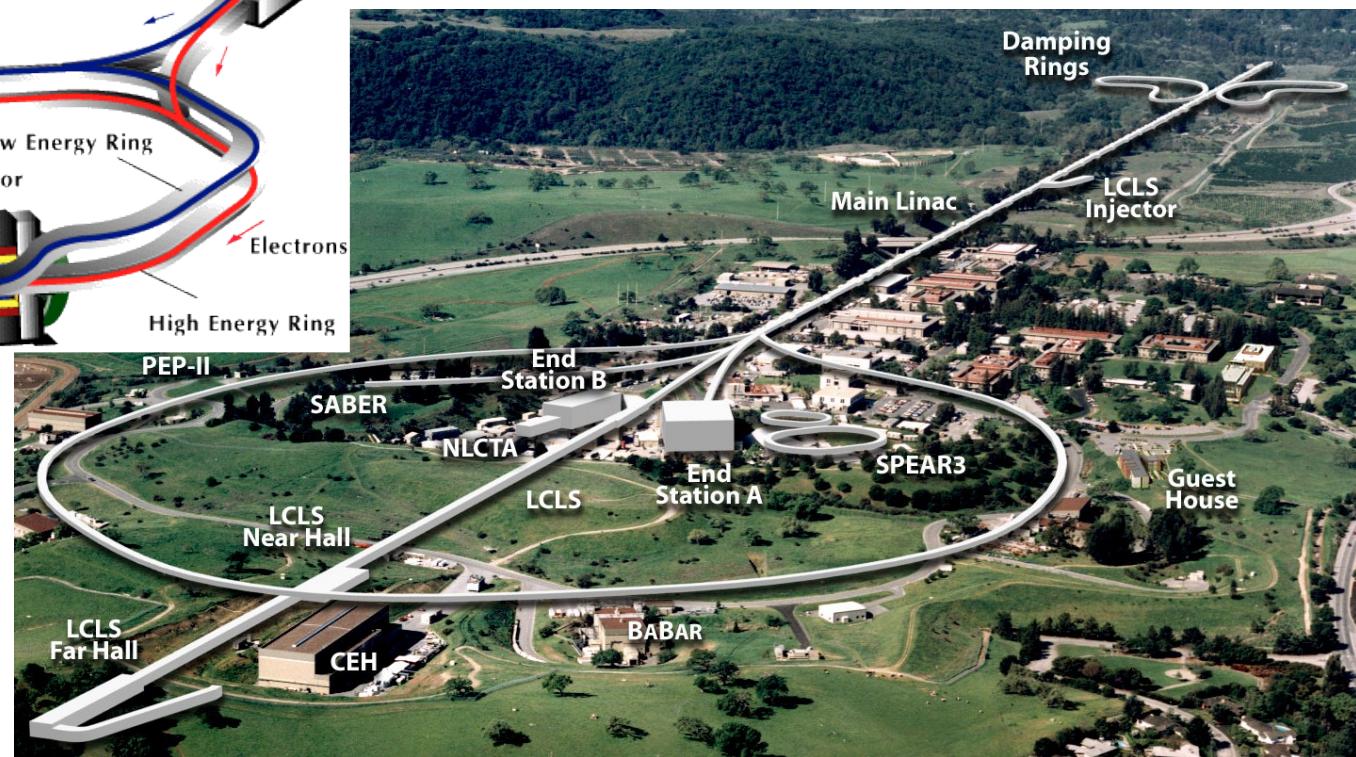
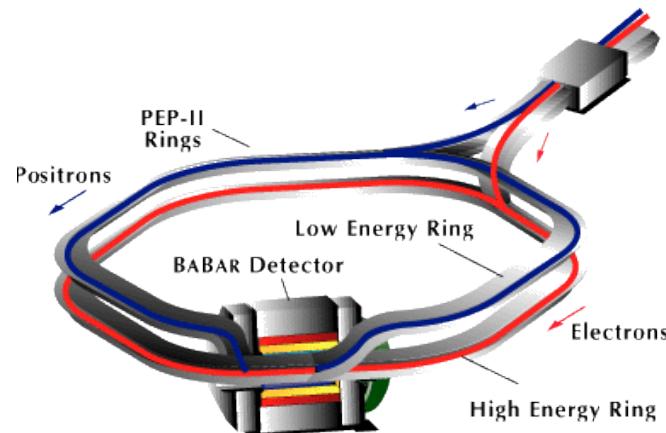
- This is unconfirmed by previous *BABAR* measurements and by measurements of other $D^{(*)}\bar{D}^{(*)}$ decay modes.
- The results of this talk are updated *BABAR* measurements and are the most precise measurements in these decay channels.

The PEP-II *B* factory

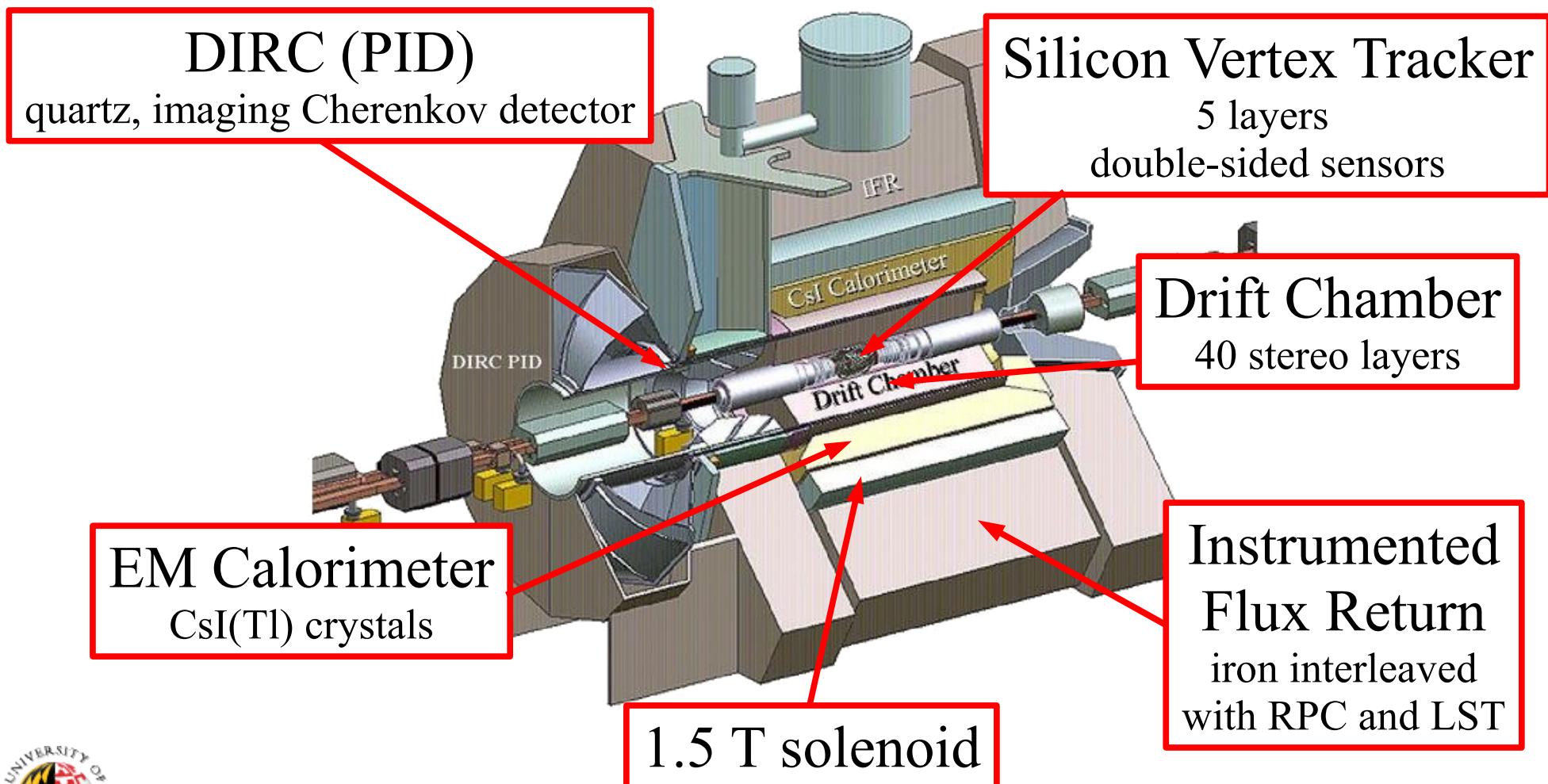
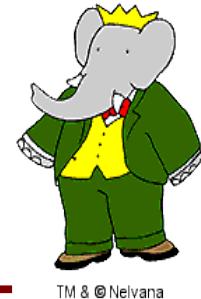


■ PEP-II *B* factory

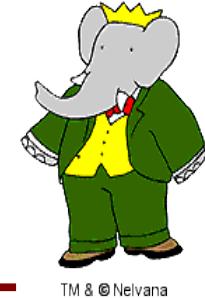
- 9 GeV e^-
- 3 GeV e^+
- e^- current 2 A
- e^+ current 3.2 A
- CM boost $\beta\gamma = 0.56$
- Peak luminosity $12 \times 10^{33} \text{ cm}^{-2}\text{s}^{-1}$



The *BABAR* detector



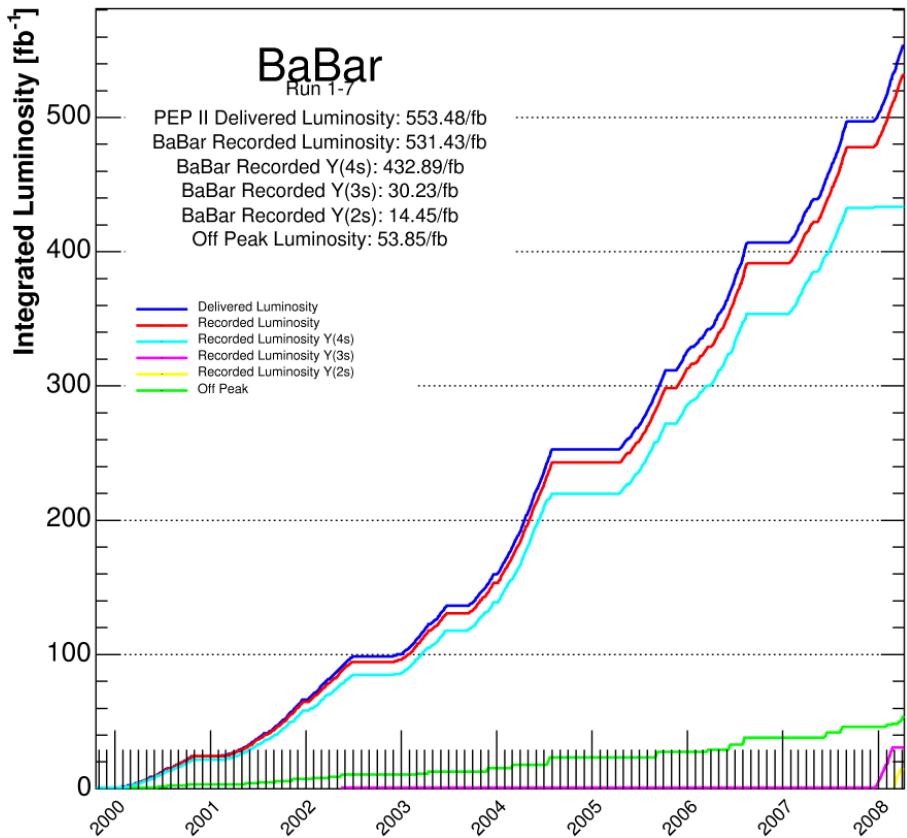
The *BABAR* dataset



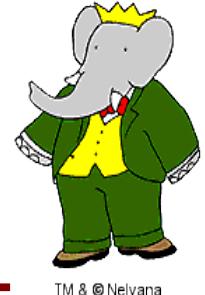
- *BABAR* spent most of its operational lifetime on the $\Upsilon(4s)$ resonance.
- *BABAR* has accumulated $(467 \pm 5) \times 10^6 B\bar{B}$ pairs
- This analysis uses the entire *BABAR* data sample

- *BABAR* retired April 7, 2008

As of 2008/04/11 00:00



$B^0 \rightarrow D^{(*)+}D^{*-}$ signal selection

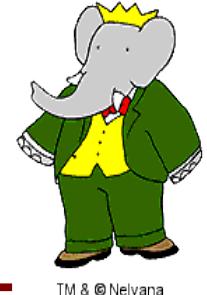


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- $B^0 \rightarrow D^+D^-$
- $B^0 \rightarrow D^{*+}D^-$
- $B^0 \rightarrow D^+D^{*-}$
- $B^0 \rightarrow D^{*+}D^{*-}$
 - ◆ $D^{*+} \rightarrow D^+\pi^0$
 - ◆ $D^{*+} \rightarrow D^0\pi^+$
 - ◆ Reject candidates with two soft π^0 .
- $D^0 \rightarrow K^-\pi^+$
- $D^0 \rightarrow K^-\pi^+\pi^0$
- $D^0 \rightarrow K^-\pi^+\pi^-\pi^+$
- $D^0 \rightarrow K_S^0\pi^+\pi^-$.
- $D^+ \rightarrow K^-\pi^+\pi^+$
- $D^+ \rightarrow K_S^0\pi^+$
- Others decays
 - ◆ $K_S^0 \rightarrow \pi^+\pi^-$
 - ◆ $\pi^0 \rightarrow \gamma\gamma$

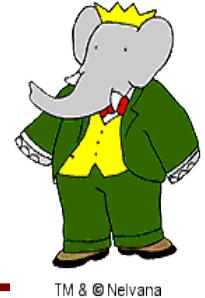


$B^0 \rightarrow D^{(*)+}D^{*-}$ signal selection

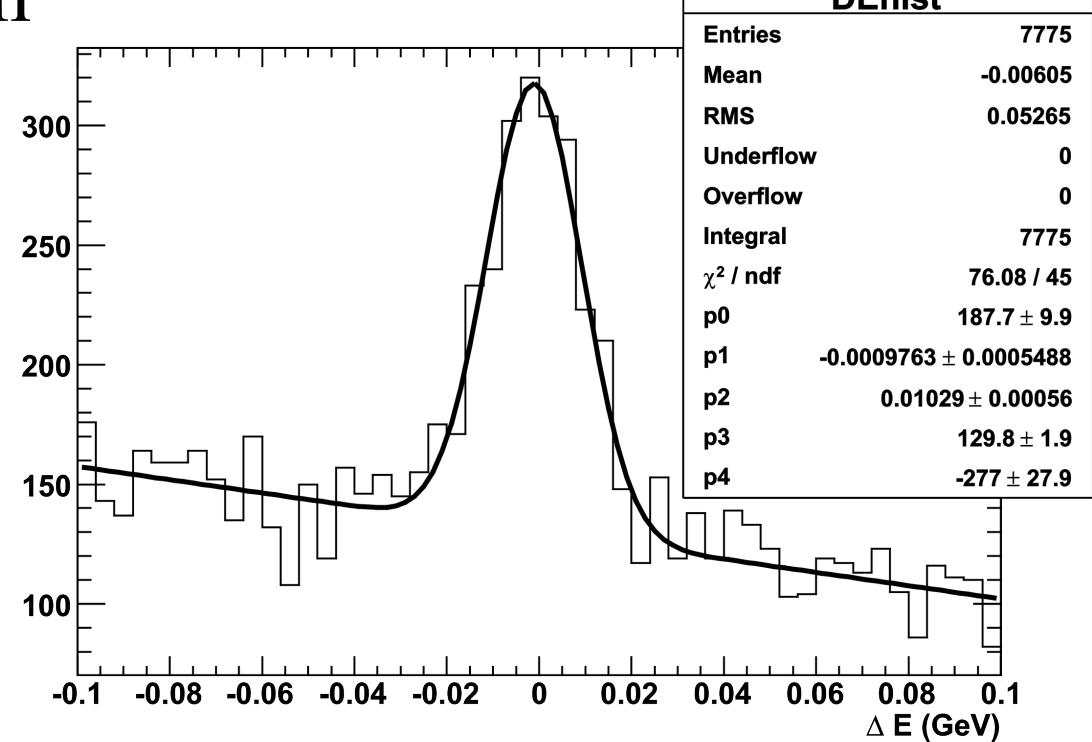


- Selection variables
 - ◆ $\Delta E = E_B - E_{\text{beam}}$ in the CM frame
 - ◆ R_2 – Ratio of second to zeroth order Fox-Wolfram moments
 - ◆ Fisher discriminant
 - ◆ Mass likelihood L_{mass}
 - ◆ D meson flight length significance
- Each D mode has its own optimized selection criteria to maximize the total signal significance for each B mode.

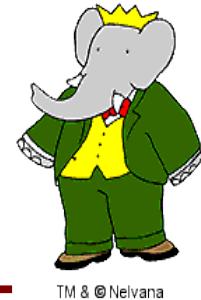
Selection variables (ΔE)



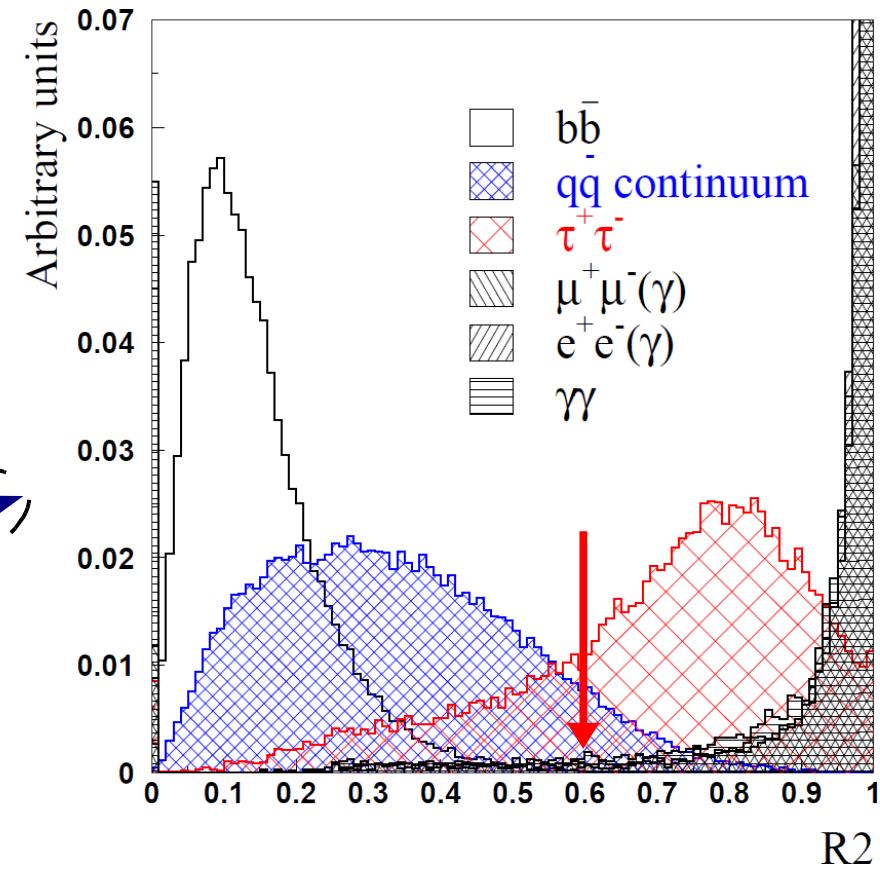
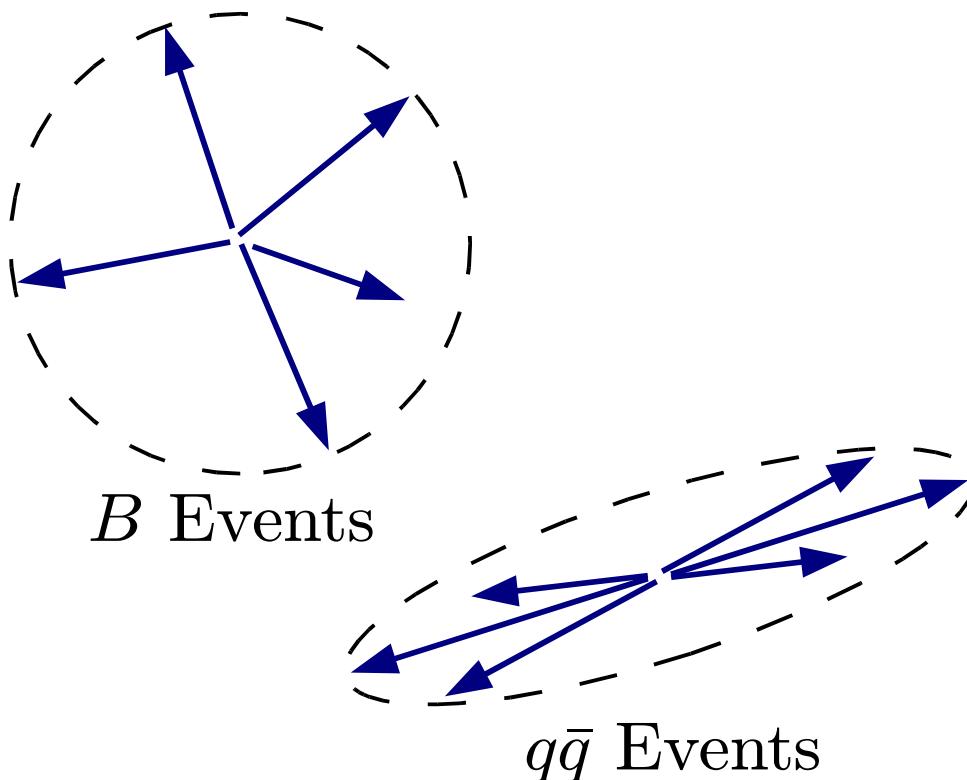
- ΔE signal peaks at zero.
- Combinatorial background is smooth linear shape.



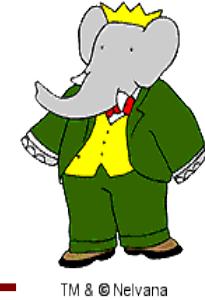
Selection Variables (R_2)



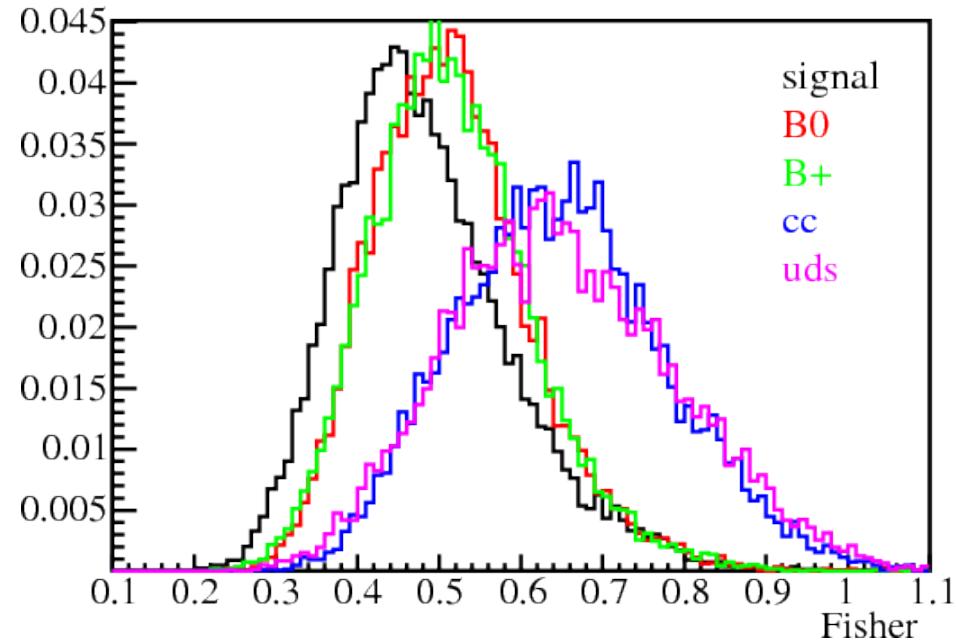
- B events have a spherical distribution, but $e^+e^- \rightarrow q\bar{q}$ continuum events are more jet-like.



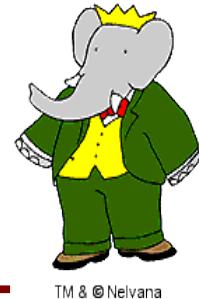
Selection variables (Fisher)



- Fisher of 11 variables
 - ◆ 9 cones of momentum
 - ◆ $|\cos\theta_T|$ of thrust axis and beam
 - ◆ $|\cos\theta_B|$ of B momentum and beam
- Used for additional suppression of the continuum background.
- Fisher variable not used for $B^0 \rightarrow D^{*+}D^{*-}$ decays.

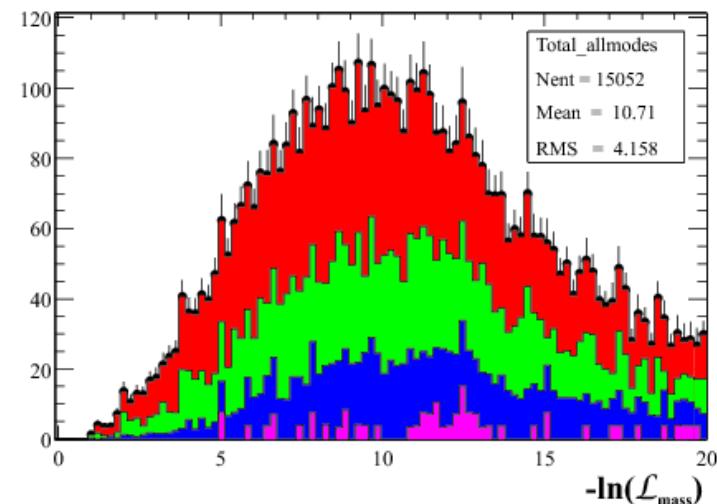
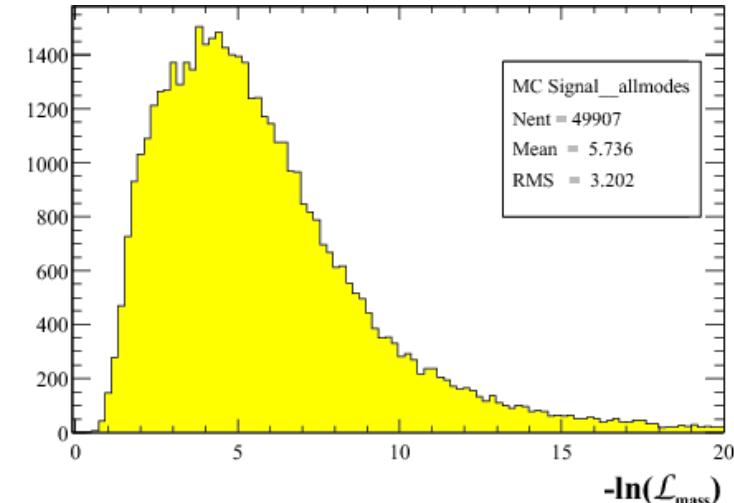


Selection variables

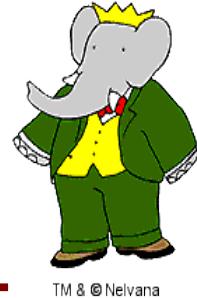


$$\begin{aligned}\mathcal{L}_{\text{mass}} = & \text{Gaussian}_{m_D} \times \text{Gaussian}_{m_{\bar{D}}} \\ & \times \text{DoubleGaussian}_{\Delta m_{D^*}} \\ & \times \text{DoubleGaussian}_{\Delta m_{\bar{D}^*}}\end{aligned}$$

- D meson Gaussian functions take widths from measured mass uncertainty.
- Double Gaussian widths taken from MC.
- In case of multiple candidates per event, best L_{mass} candidate is kept.



Extracting signal yields



- We determine signal yield from a fit to the m_{ES} distribution.

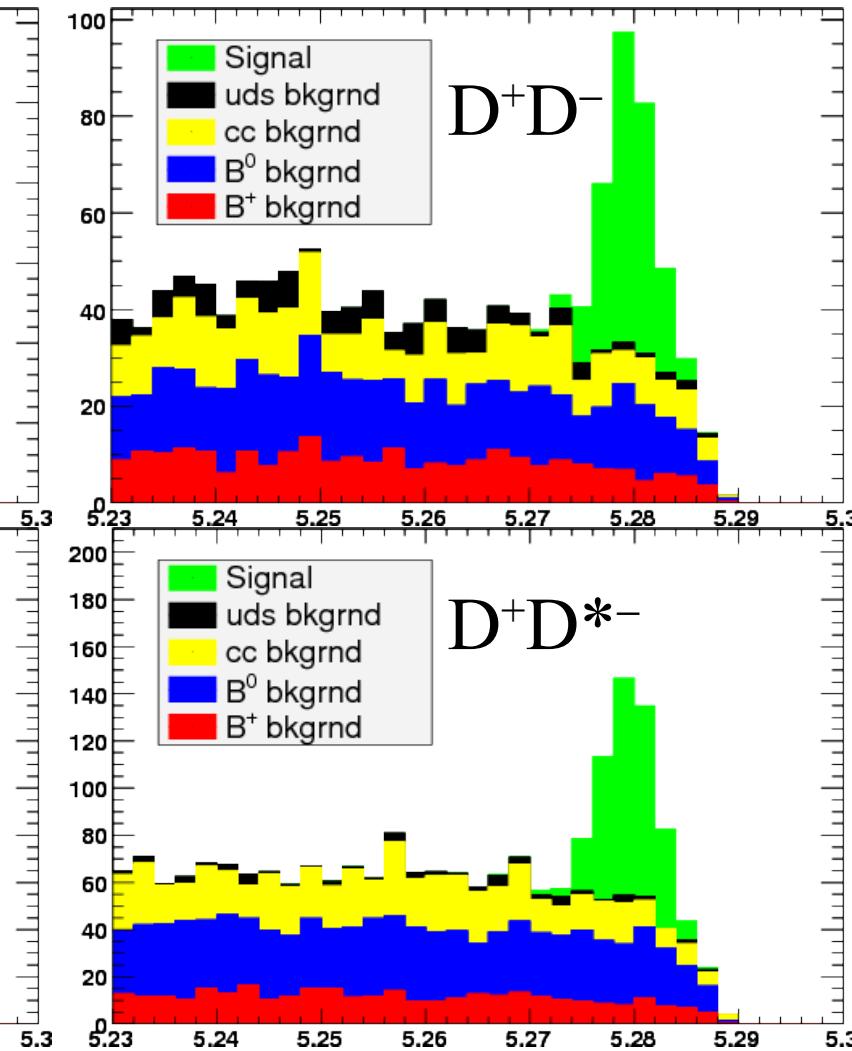
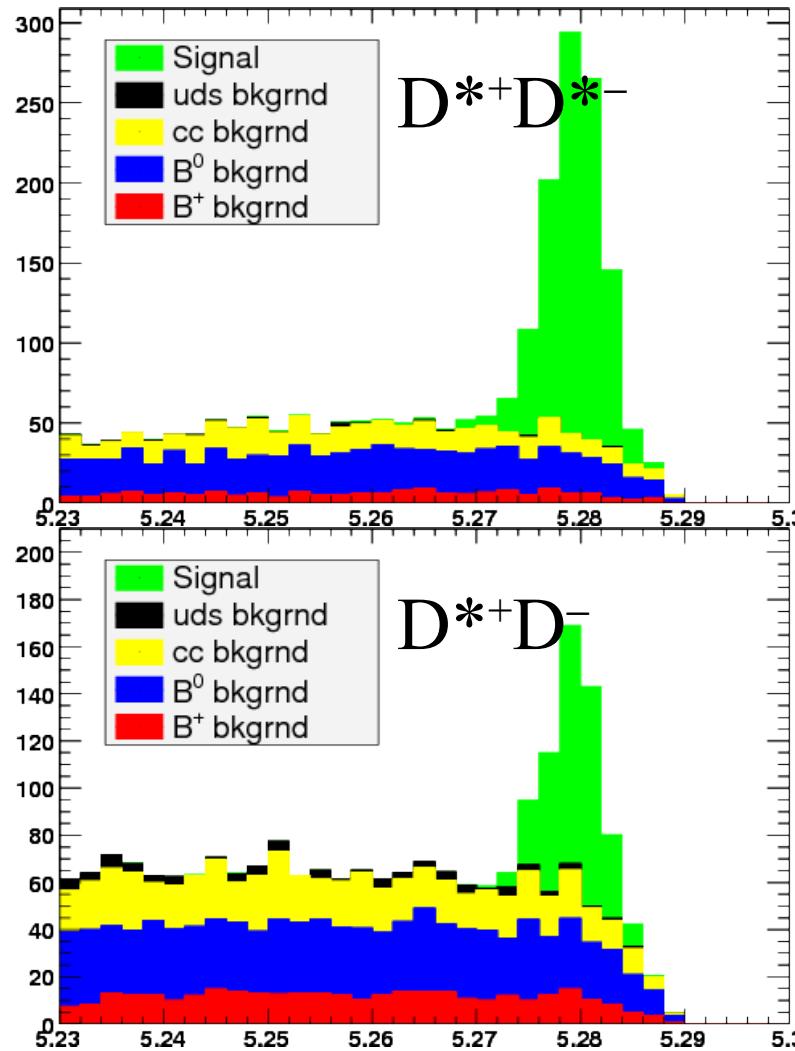
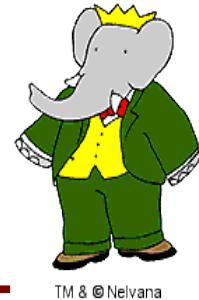
$$m_{\text{ES}} = \sqrt{(s/2 + p_{\text{beam}} \cdot p_B)^2 / E_{\text{beam}}^2 - p_B^2}$$

- Signal is a Gaussian shape.
 - ◆ Fixed widths from signal MC for D^+D^- , $D^{*+}D^-$, and D^+D^{*-} .
 - ◆ Width is free parameter for $D^{*+}D^{*-}$.
- Background is a threshold function.

$$f_{m_{\text{ES}}, \text{bg}} = m_{\text{ES}} e^{\kappa(1 - 4m_{\text{ES}}^2/s)} \sqrt{1 - 4m_{\text{ES}}^2/s}$$



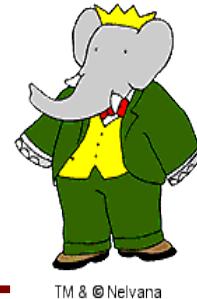
Background composition



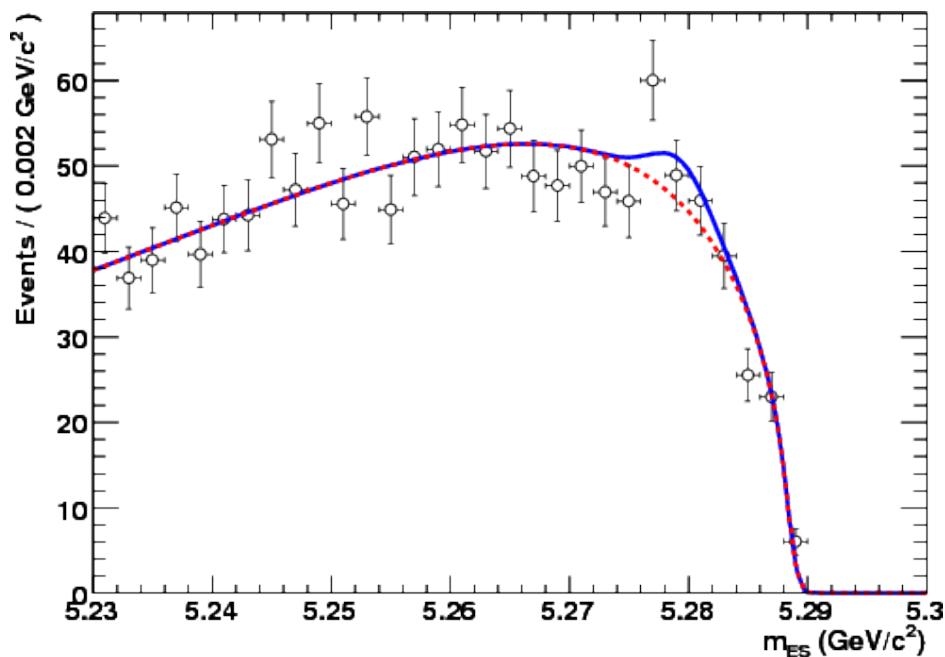
$D^{*+}D^-$

D^+D^{*-}

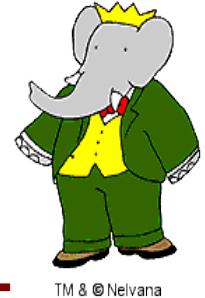
Peaking Background



- MC reveals that there is a small background component which is not well modeled by a pure threshold shape.
- Fix the size relative to the signal peak to MC expectations.
- For example, $B^0 \rightarrow D^{*+}D^{*-}$ comes from $B^- \rightarrow D^{*0}D^{*-}$.

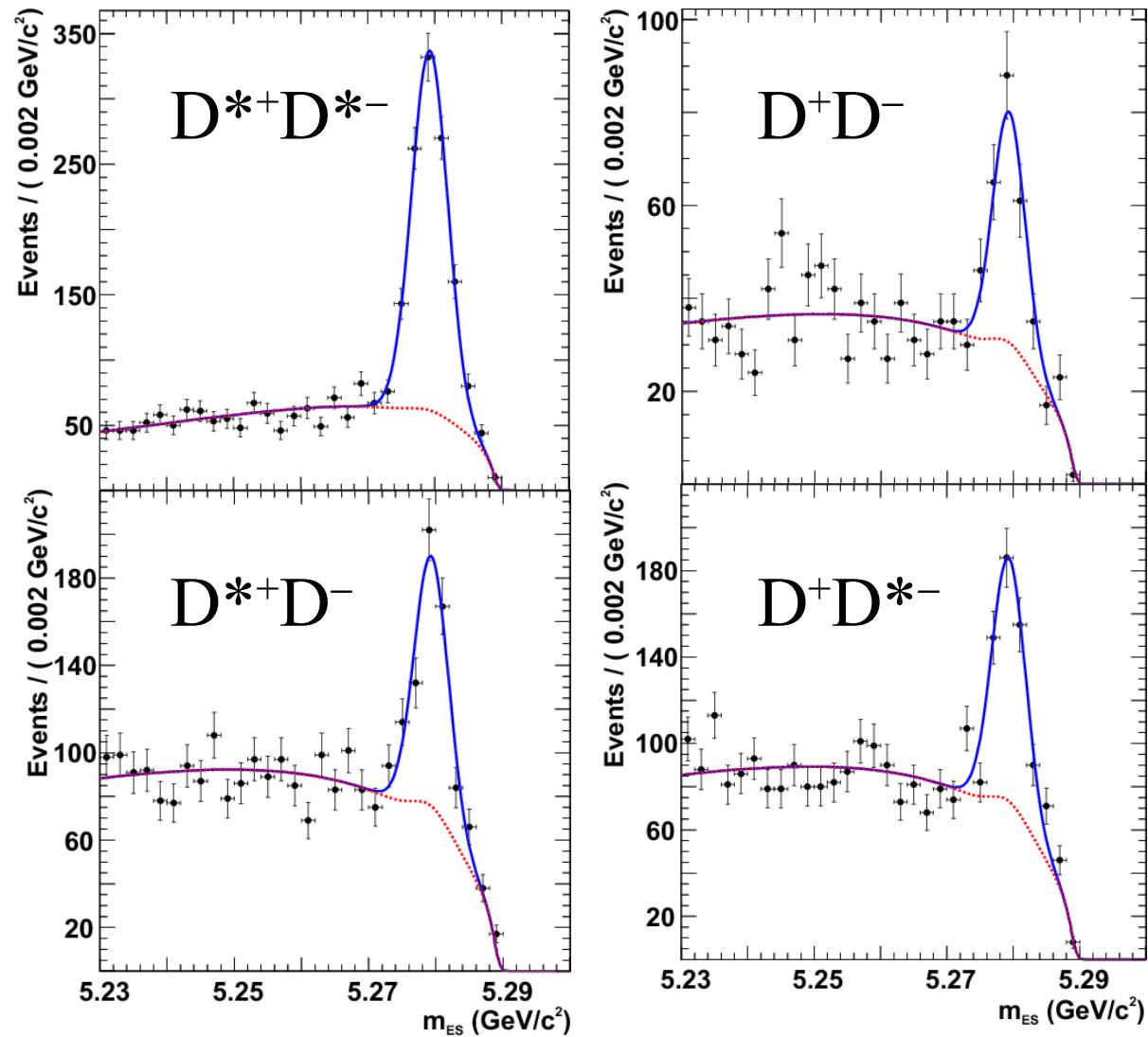


Signal yields

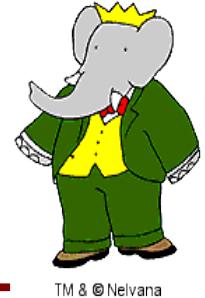


■ Yields

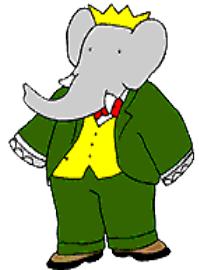
- ◆ $D^{*+}D^{*-}$
 934 ± 40
- ◆ D^+D^-
 152 ± 17
- ◆ $D^{*+}D^-$
 365 ± 26
- ◆ D^+D^{*-}
 359 ± 26



Analysis outline



- Angular analysis of the $B^0 \rightarrow D^{*+}D^{*-}$ decays.
 - ◆ Model detector efficiency and resolution.
 - ◆ Extract the CP-odd fraction.
- Time-dependent CP measurements
 - ◆ Model detector vertex resolution and tagging performance.
 - ◆ Extract C and S parameters for each decay channels.

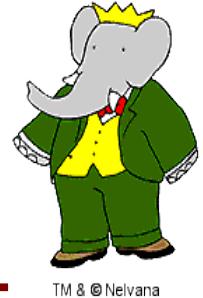


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$B^0 \rightarrow D^{*+}D^{*-}$ angular analysis



The transversity basis



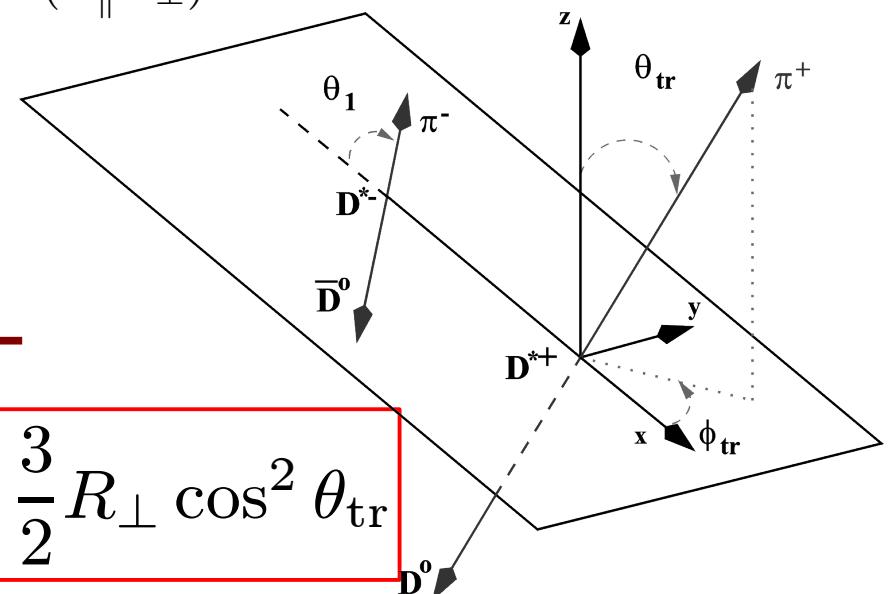
$$\frac{1}{\Gamma} \frac{d^4\Gamma}{d \cos \theta_1 d \cos \theta_{tr} d\phi_{tr} dt} = \frac{9}{16\pi} \frac{1}{|A_0|^2 + |A_{||}|^2 + |A_{\perp}|^2} \times$$

$$\left\{ 2 \cos^2 \theta_1 \sin^2 \theta_{tr} \cos^2 \phi_{tr} |A_0|^2 + \sin^2 \theta_1 \sin^2 \theta_{tr} \sin^2 \phi_{tr} |A_{||}|^2 \right.$$

$$+ \sin^2 \theta_1 \cos^2 \theta_{tr} |A_{\perp}|^2 - \sin^2 \theta_1 \sin 2\theta_{tr} \sin \phi_{tr} \text{Im}(A_{||}^* A_{\perp})$$

$$+ \frac{1}{\sqrt{2}} \sin 2\theta_1 \sin^2 \theta_{tr} \sin 2\phi_{tr} \text{Re}(A_0^* A_{||})$$

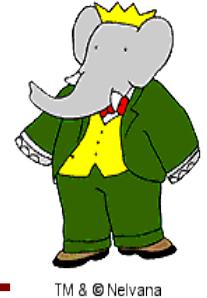
$$\left. - \frac{1}{\sqrt{2}} \sin 2\theta_1 \sin 2\theta_{tr} \cos \phi_{tr} \text{Im}(A_0^* A_{\perp}) \right\}$$



$$\boxed{\frac{1}{\Gamma} \frac{d\Gamma}{d \cos \theta_{tr}}} = \frac{3}{4} (1 - R_{\perp}) \sin^2 \theta_{tr} + \frac{3}{2} R_{\perp} \cos^2 \theta_{tr}$$

$$R_{\perp} = \frac{|A_{\perp}^0|^2}{|A_0^0|^2 + |A_{||}^0|^2 + |A_{\perp}^0|^2}$$

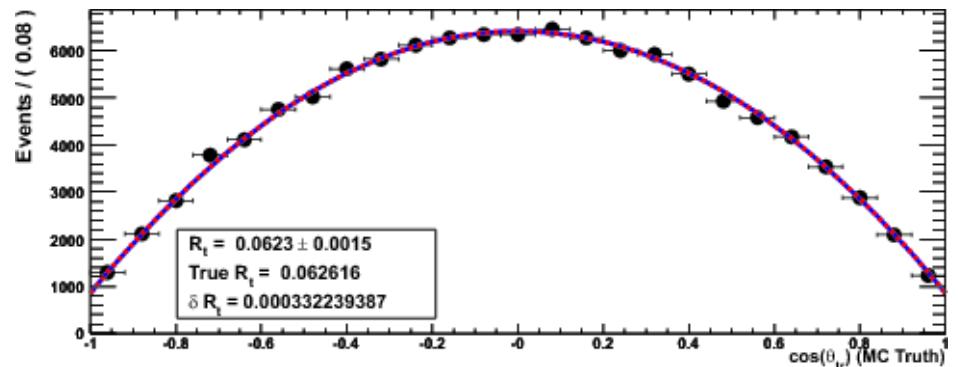
Transversity analysis



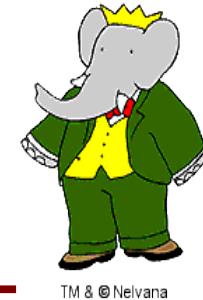
- R_{\perp} can be measured from the distribution of $\cos\theta_{\text{tr}}$.
- Experimental effects change the distribution.
 - ◆ Detector efficiency
 - ◆ Measurement resolution
 - ◆ Parameters of the model split by slow π charges

$$\begin{aligned}\mathcal{F}(\cos\theta_{\text{tr}}) = & \left\{ \frac{3}{4}(1 - R_{\perp}) \sin^2\theta_{\text{tr}} \right. \\ & \times \left[\frac{1 + \alpha}{2} I_0(\cos\theta_{\text{tr}}) + \frac{1 - \alpha}{2} I_{\parallel}(\cos\theta_{\text{tr}}) \right] \\ & \left. + \frac{3}{2} R_{\perp} \cos^2\theta_{\text{tr}} \times I_{\perp}(\cos\theta_{\text{tr}}) \right\} \otimes \mathcal{R}(\Delta\theta_{\text{tr}})\end{aligned}$$

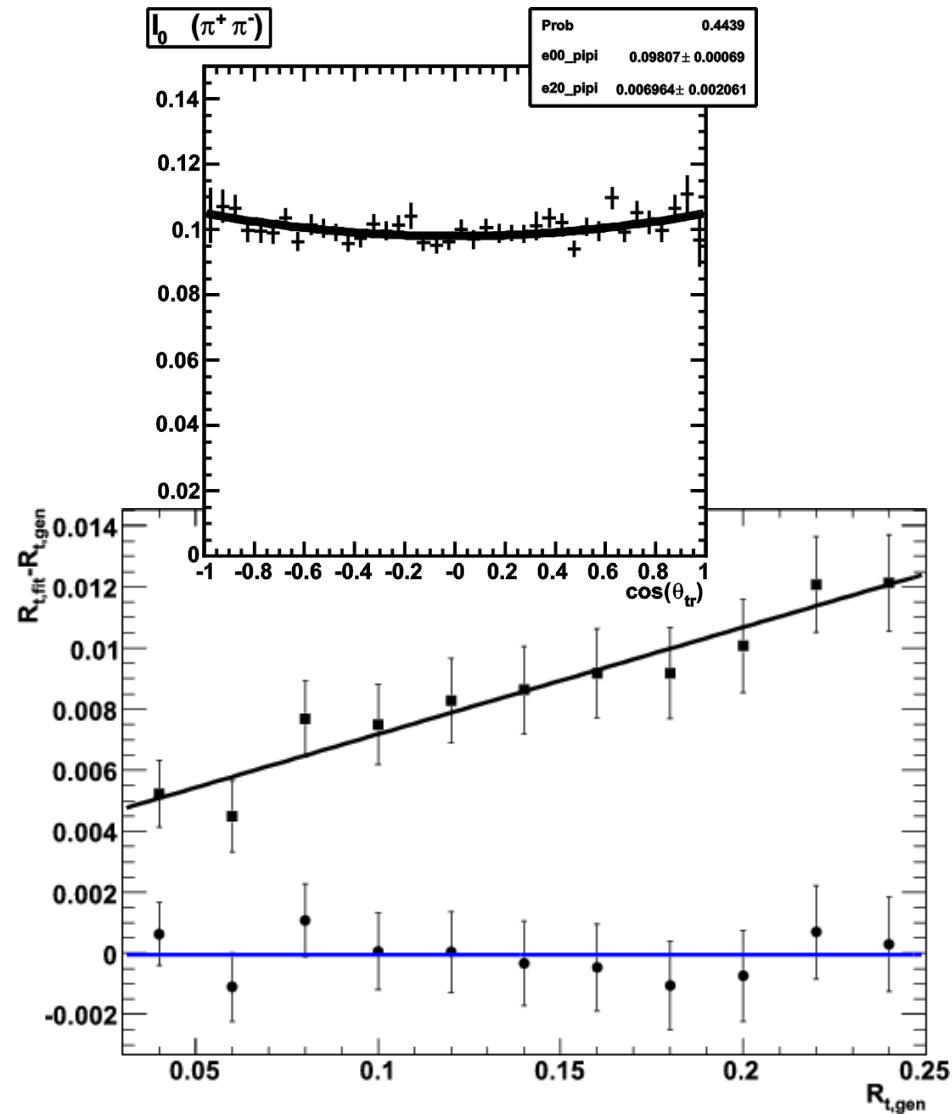
$$\alpha = \frac{|A_0^0|^2 - |A_{\parallel}^0|^2}{|A_0^0|^2 + |A_{\parallel}^0|^2}$$



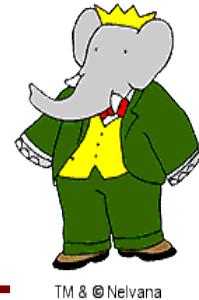
Detector efficiency moments



- Efficiency is due primarily to loss of efficiency for pions with $p_T < 55 \text{ MeV}/c$.
- Each moment is modeled as 2nd order even polynomial in $\cos\theta_{tr}$.
- Shapes fixed from MC.
- Neglecting efficiency moments leads to a small bias in R_\perp .



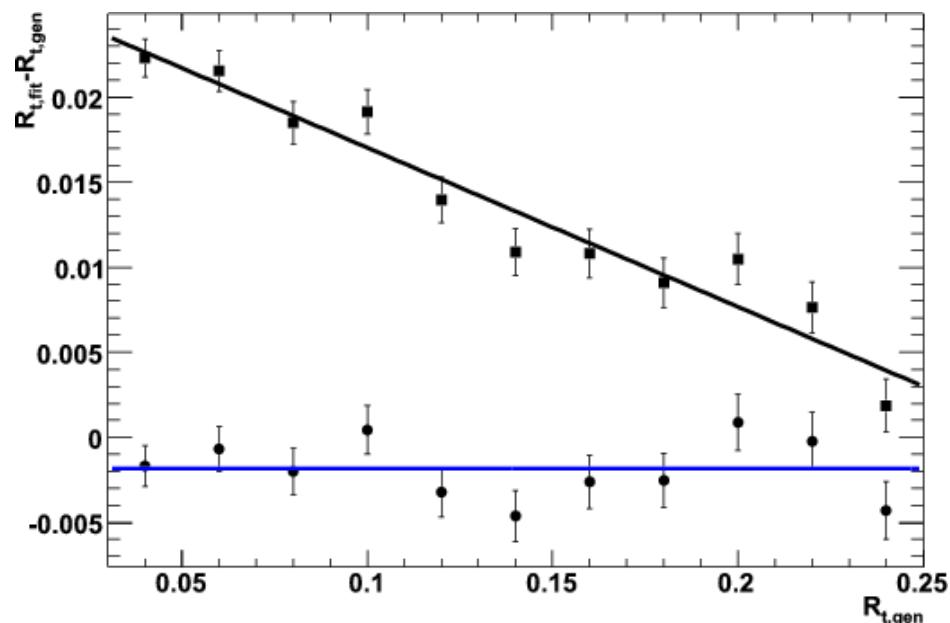
Angular measurement resolution



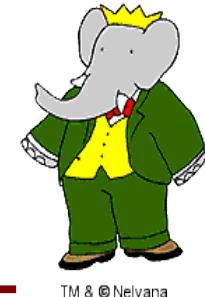
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- Measurement resolution smears the $\cos\theta_{\text{tr}}$ distribution.
- Resolution is parameterized as a function of θ_{tr} .
- We find an additional component from poorly reconstructed π where the value of θ_{tr} is uncorrelated with the true value.
- Sum of 3 Gaussian functions for the resolution.

- A truncated Gaussian shape centered at $\pi/2$ for the uncorrelated component.
- Shapes fixed from MC.

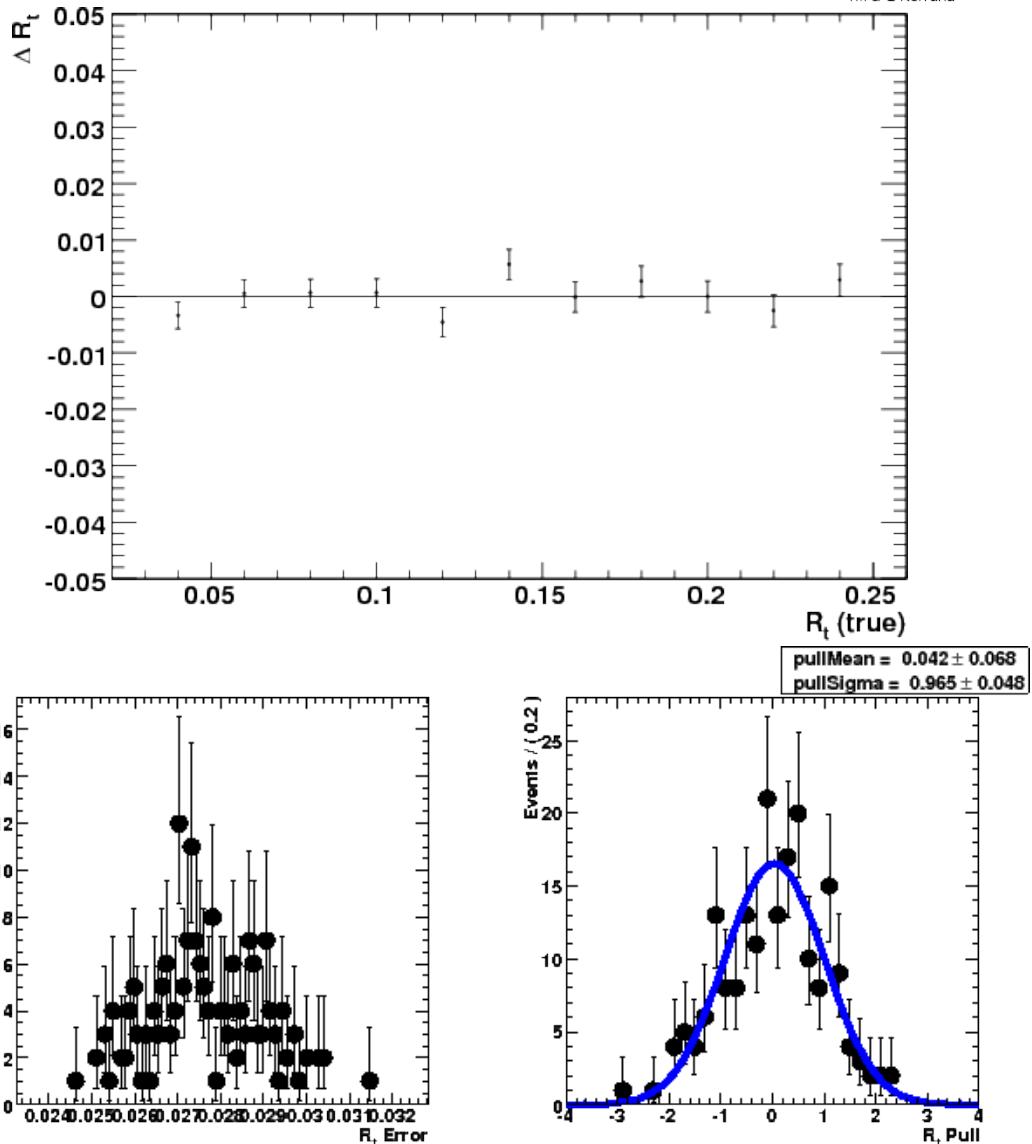


Fit validation

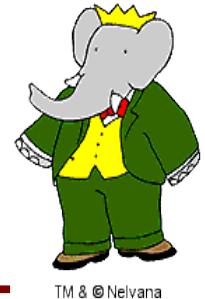


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- Simultaneous fit to $\cos\theta_{tr}$ and m_{ES} distributions.
- Validated using MC.
- No bias and reasonable uncertainties observed.



Result



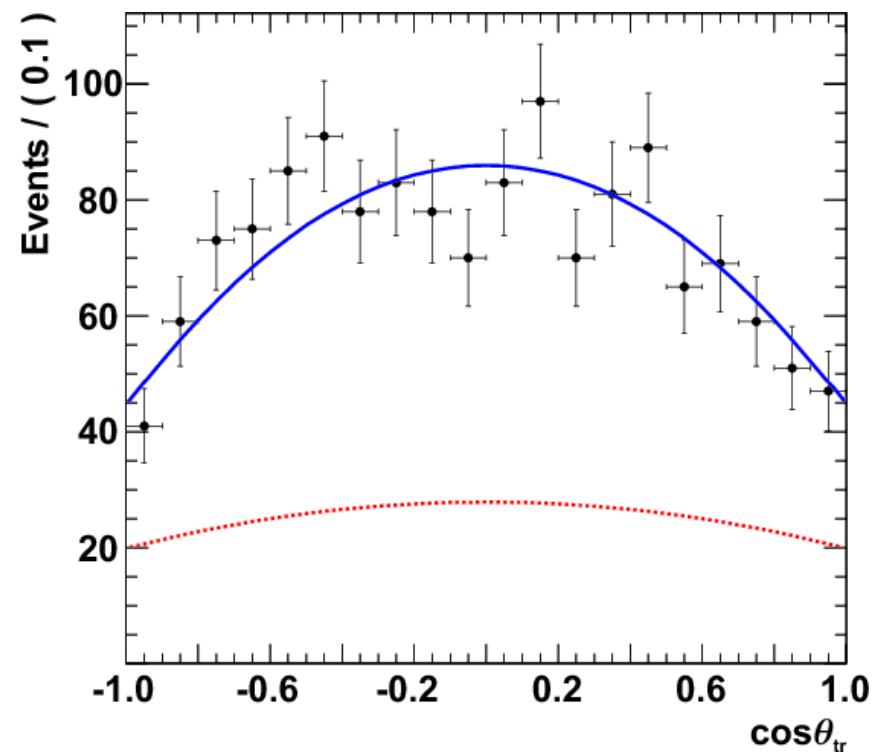
- Fit result

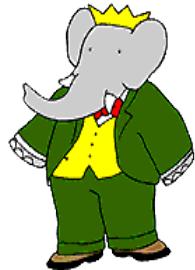
$$R_{\perp} = 0.158 \pm 0.028 \pm 0.006$$

Dilution of 0.684

- Systematics

Source	uncertainty
Angular resolution	0.001
Uncorrelated model	0.004
Efficiency moments	0.002
α parameter	0.003
Peaking background	0.001
Background model	0.0002
Potential fit bias	0.002
Total	0.006



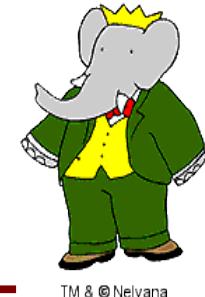


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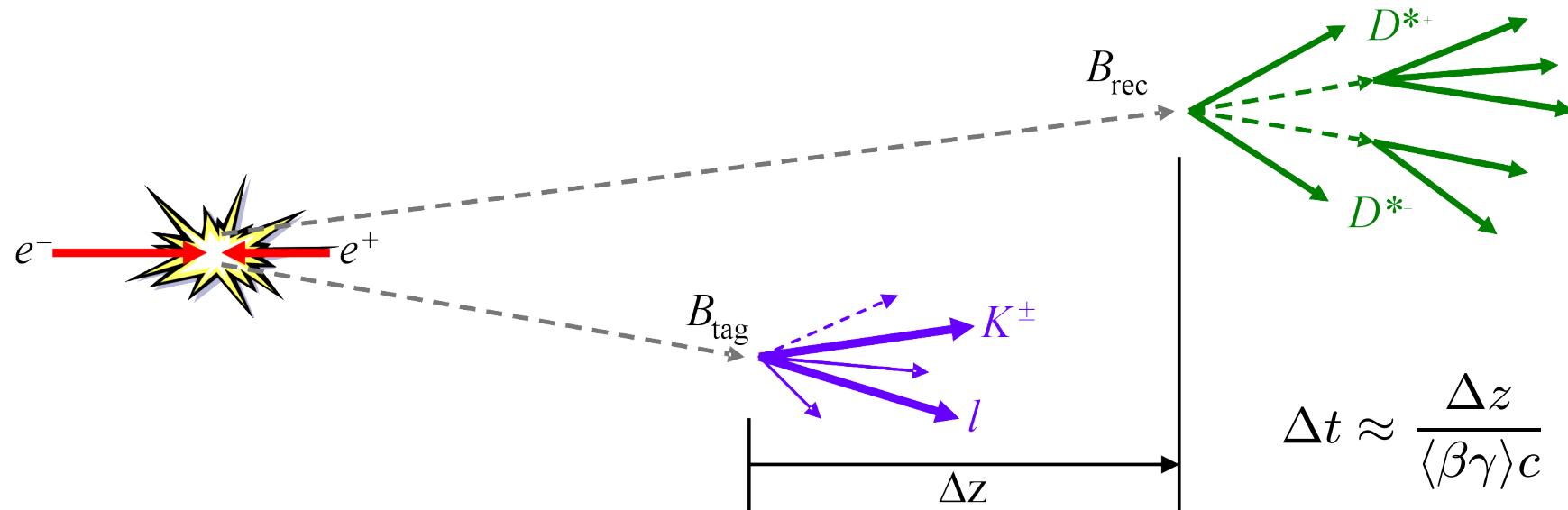
Time-dependent CP violation measurement



Measuring Δt

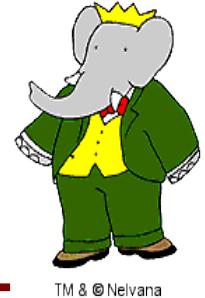


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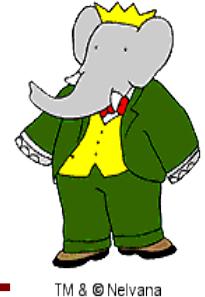
- Using the boost of the CM frame with respect to the detector, we can measure Δz and convert that to Δt .
- The uncertainty of each vertex is used as an uncertainty on Δt .

B flavor tagging

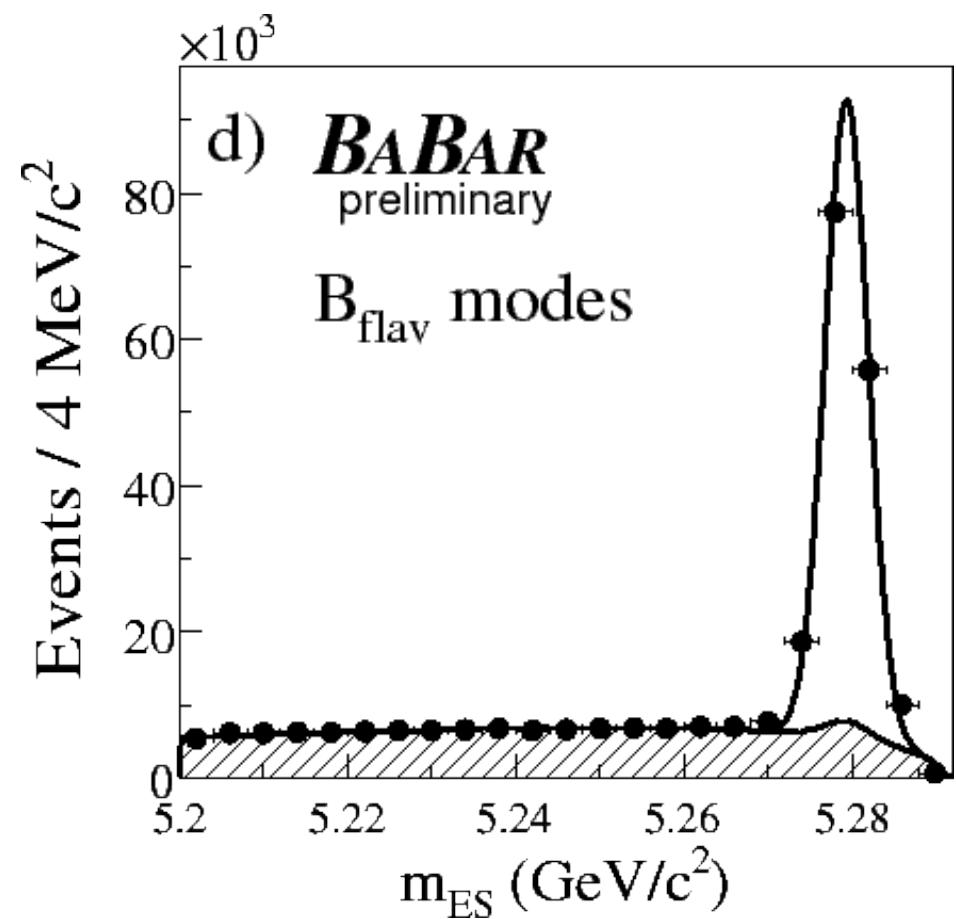


- Using the daughters of the B_{tag} meson, we identify the flavor at the time of its decay.
 - ◆ leptons from semi-leptonic b decays.
 - ◆ kaons from the $b \rightarrow c \rightarrow s$ transitions.
 - ◆ pions and kaons from D^* decays.
- The *BABAR* tagging routine, using a series of neural networks, achieves $(74.3 \pm 0.1)\%$ tagging efficiency and effective tagging efficiency $Q = \varepsilon_{\text{tag}}(1-2w)^2$ of 31.2%.

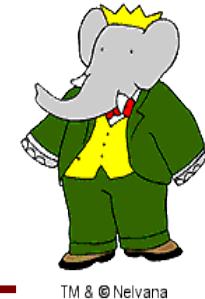
Vertexing and tagging performance



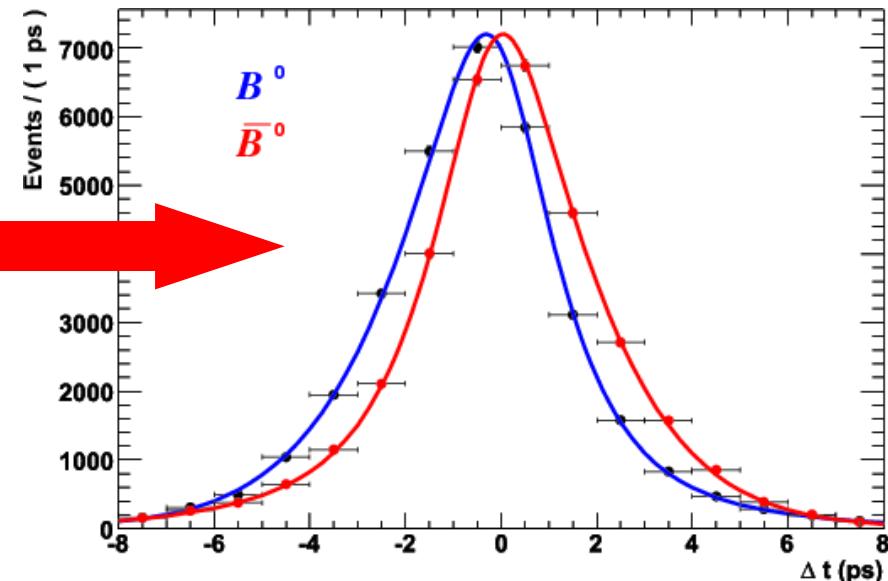
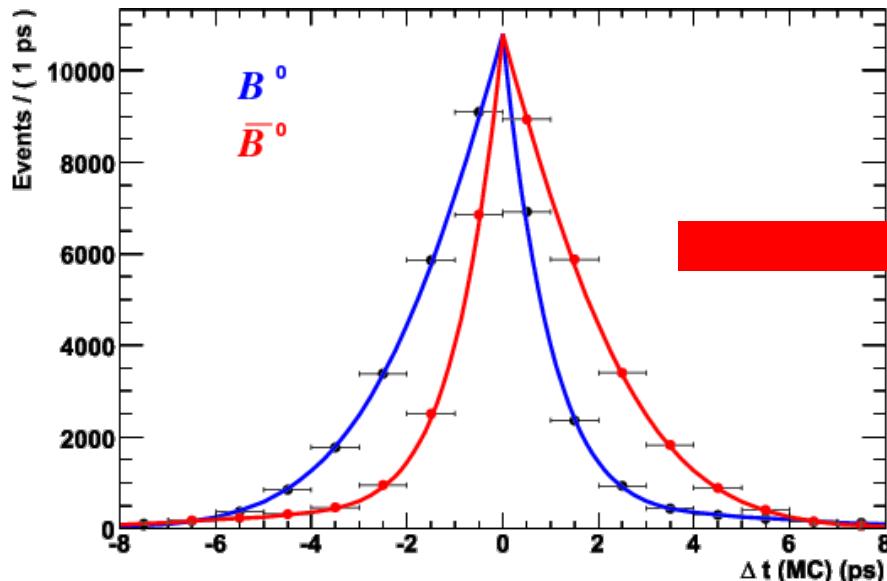
- A data sample of flavor eigenstate decays $B^0 \rightarrow D^{(*)-} h^+$ ($h^+ = \pi^+, \rho^+, a_1^+$).
- We constrain the mis-tag probabilities w .
- We determine the parameters of the Δt measurement resolution.



Δt resolution

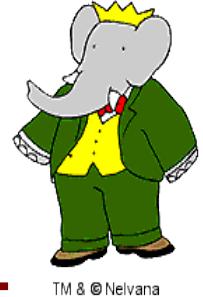


- Finite vertex resolution translates into a smearing of the usually sharp Δt distributions.
- Resolution modeled as sum of 3 Gaussian functions.



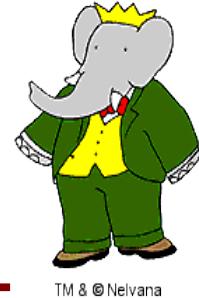
$$\sin 2\beta = 0.7$$

Signal distributions



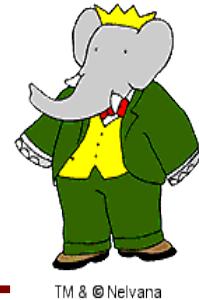
- D^+D^- , $D^{*+}D^-$, and D^+D^{*-}
 - ◆ $\mathcal{F}_\pm(\Delta t) \propto e^{-|\Delta t|/\tau_{B^0}} \{(1 \mp \Delta w) \pm (1 - 2w) \times [S \sin(\Delta m_d \Delta t) - C \cos(\Delta m_d \Delta t)]\} \otimes \mathcal{R}(\Delta t - \Delta t')$
- $D^{*+}D^{*-}$
 - ◆ $\mathcal{F}_\pm(\cos \theta_{\text{tr}}, \Delta t) \propto e^{-|\Delta t|/\tau_{B^0}} \{F(1 \mp \Delta w) \pm (1 - 2w) \times [G \sin(\Delta m_d \Delta t) - H \cos(\Delta m_d \Delta t)]\} \otimes \mathcal{R}(\Delta t - \Delta t') \otimes \mathcal{R}(\Delta \theta_{\text{tr}})$
$$F = (1 - R_\perp) \sin^2 \theta_{\text{tr}} + 2R_\perp \cos^2 \theta_{\text{tr}}$$
$$G = (1 - R_\perp) S_+ \sin^2 \theta_{\text{tr}} - 2R_\perp S_\perp \cos^2 \theta_{\text{tr}}$$
$$H = (1 - R_\perp) C_+ \sin^2 \theta_{\text{tr}} + 2R_\perp C_\perp \cos^2 \theta_{\text{tr}}$$

Background distributions

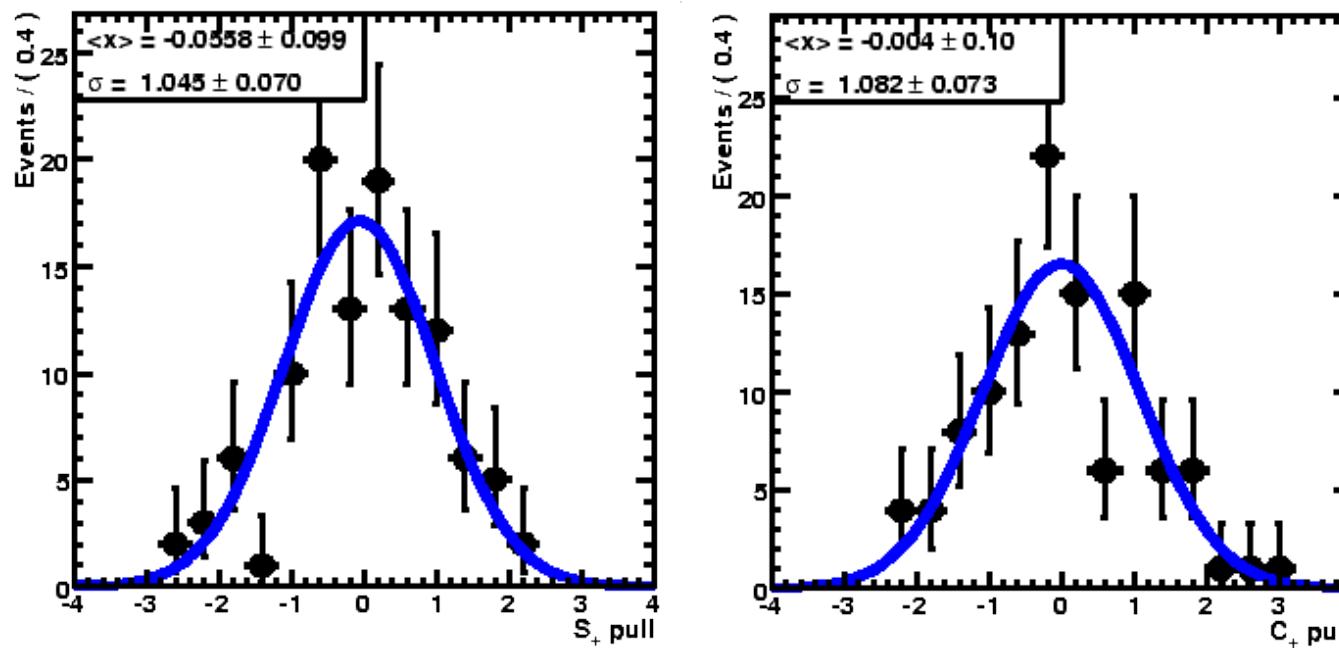


- The background shapes are constrained in the fit by the m_{ES} sideband.
 - ◆ The Δt background distribution is allowed to have effective CP parameters, $C_{bg,eff}$ and $S_{bg,eff}$.
 - ◆ The $\cos\theta_{tr}$ background uses the same shape as the transversity analysis.

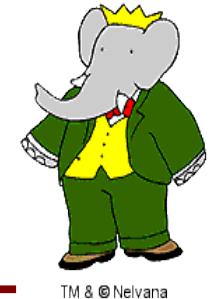
Fit validation



- Validate fit using MC.
- We see no bias and find reasonable uncertainties.



Results $D^{*+}D^{*-}$



- Fit results

$$S_+ = -0.76 \pm 0.16 \pm 0.04$$

$$C_+ = +0.00 \pm 0.12 \pm 0.02$$

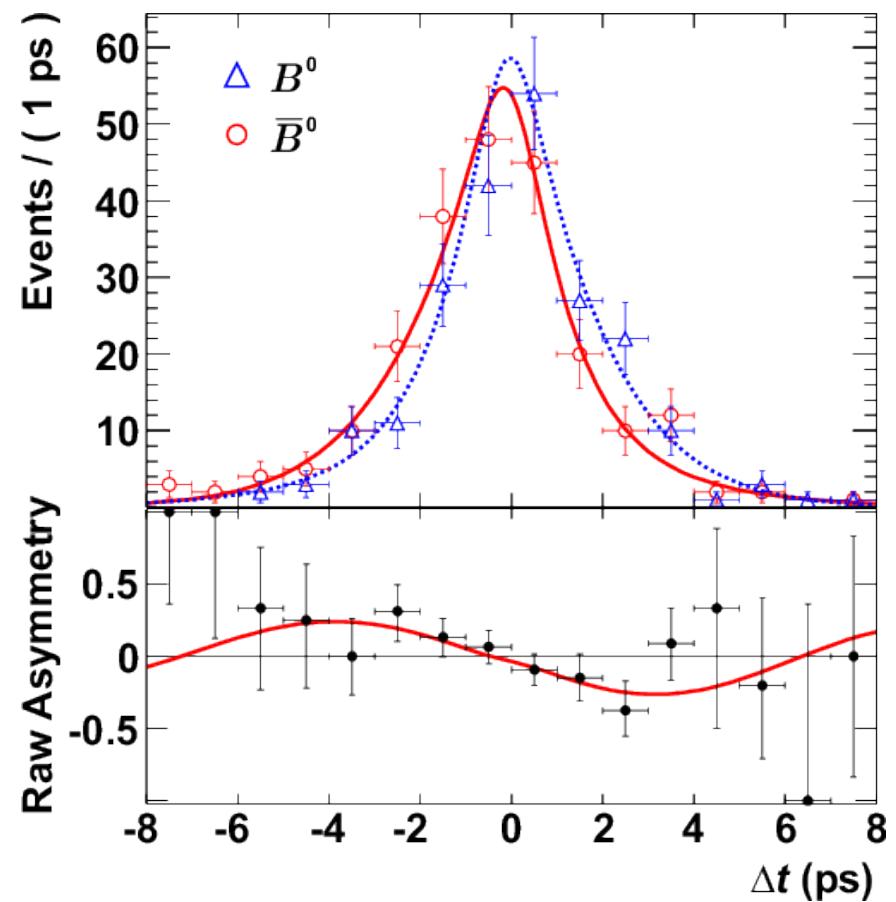
$$S_\perp = -1.80 \pm 0.70 \pm 0.16$$

$$C_\perp = +0.41 \pm 0.49 \pm 0.08$$

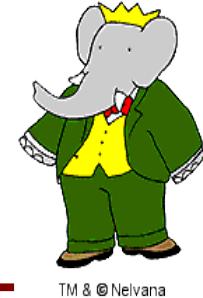
- Constraining S and C

$$S_{D^{*+}D^{*-}} = -0.70 \pm 0.16 \pm 0.03$$

$$C_{D^{*+}D^{*-}} = +0.05 \pm 0.09 \pm 0.02$$



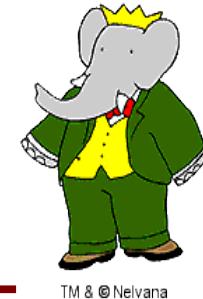
Systematics $D^{*+}D^{*-}$



	S_+	S_\perp	C_+	C_\perp	$S_{D^*+D^*-}$	$C_{D^*+D^*-}$
Tagging and Δt resolution	0.022	0.031	0.010	0.017	0.021	0.009
Peaking background	0.012	0.079	0.002	0.019	0.012	0.003
Detector Alignment	0.006	0.029	0.001	0.019	0.005	0.002
DCS decays	0.002	0.002	0.014	0.014	0.002	0.014
Potential Fit Bias	0.011	0.098	0.008	0.065	0.011	0.007
Angular PDF variations	0.025	0.091	0.004	0.015	0.011	0.001
Other	0.013	0.025	0.005	0.029	0.013	0.002
Total	0.040	0.163	0.020	0.080	0.032	0.018

- Perturb fixed parameters relating to tagging and resolution.
- The detector alignment systematic comes from perturbing the nominal SVT positions and studying the effects on CP parameters
- Doubly-Cabbibo suppressed (DCS) decays pollute the tag side when using kaons and pions for flavor tagging.

Results D⁺D⁻



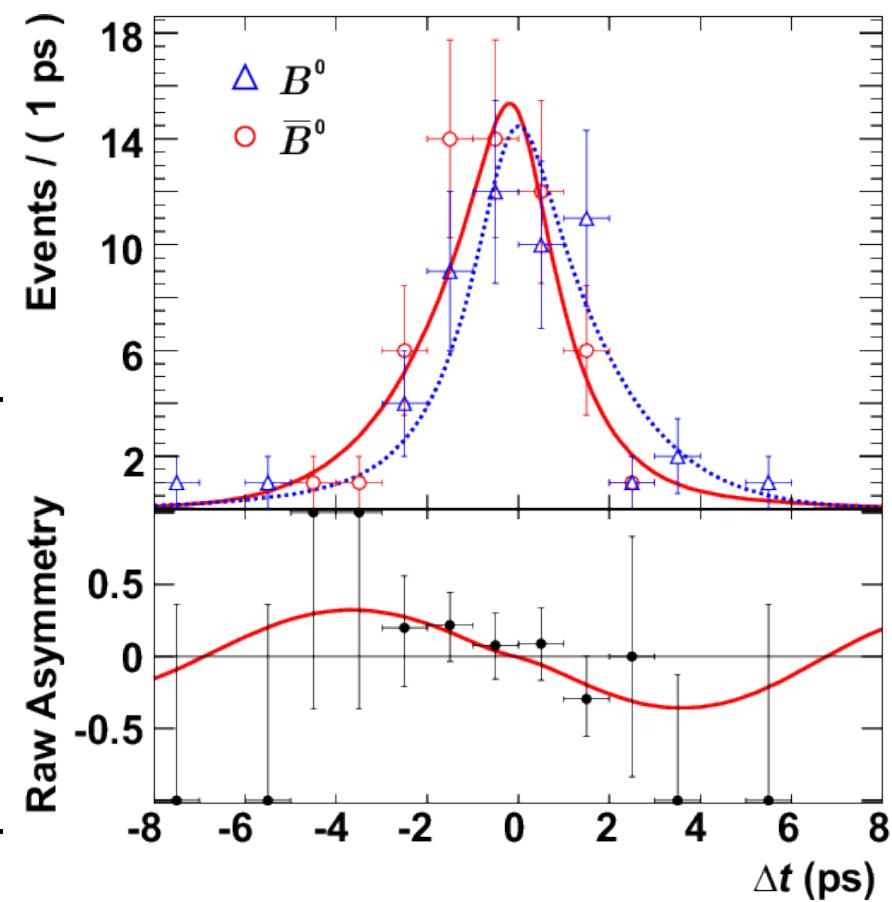
- Fit results

$$S_{D^+D^-} = -0.63 \pm 0.36 \pm 0.05$$

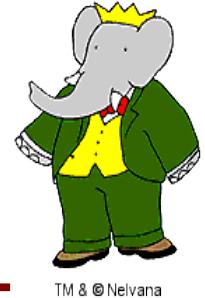
$$C_{D^+D^-} = -0.07 \pm 0.23 \pm 0.03$$

- Systematics

	<i>S</i>	<i>C</i>
Tagging and Δt resolution	0.031	0.011
m_{ES} signal width	0.034	0.020
Peaking background	0.018	0.007
Detector Alignment	0.002	0.001
DCS decays	0.002	0.014
Potential Fit Bias	0.007	0.005
Other	0.006	0.002
Total	0.051	0.028



Results $D^{*\pm}D^{\mp}$



- Fit Results

$$S_{D^{*+}D^-} = -0.62 \pm 0.21 \pm 0.03$$

$$S_{D^+D^{*-}} = -0.73 \pm 0.23 \pm 0.05$$

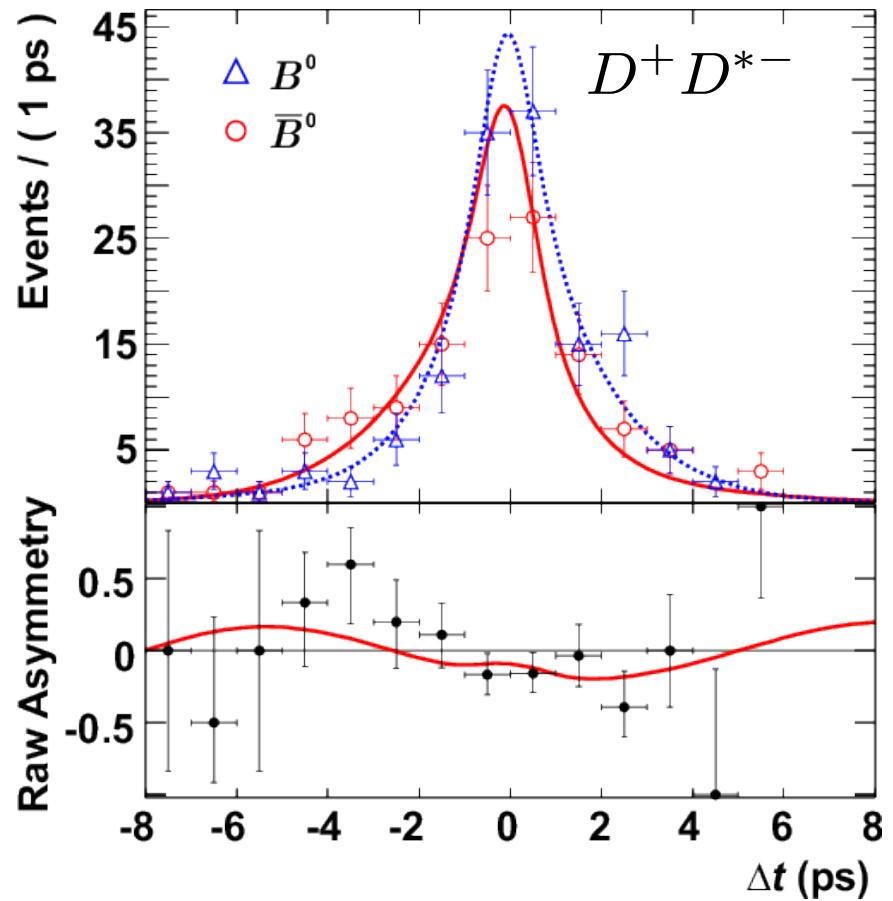
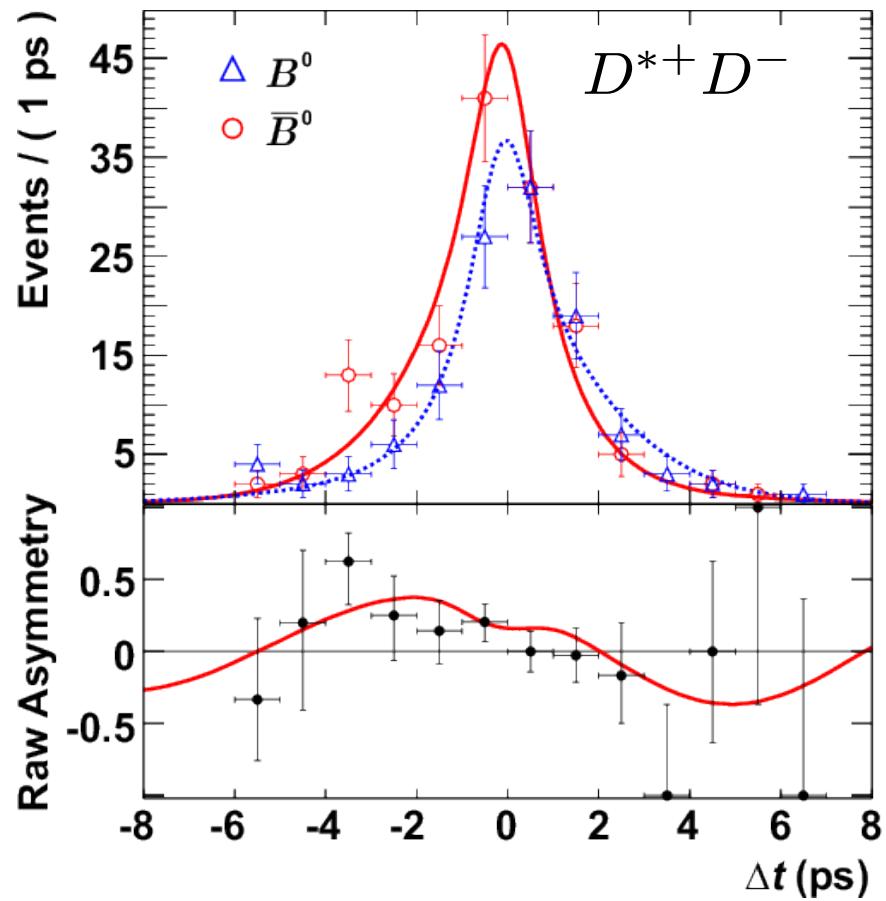
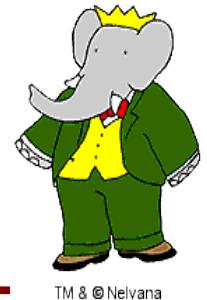
$$C_{D^{*+}D^-} = +0.08 \pm 0.17 \pm 0.04$$

$$C_{D^+D^{*-}} = +0.00 \pm 0.17 \pm 0.03$$

- Systematics

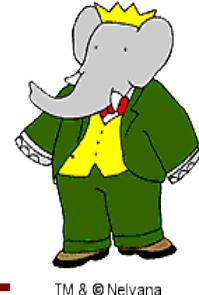
	$S_{D^{*+}D^-}$	$C_{D^{*+}D^-}$	$S_{D^+D^{*-}}$	$C_{D^+D^{*-}}$
Tagging and Δt resolution	0.027	0.012	0.029	0.011
m_{ES} signal width	0.013	0.018	0.028	0.012
Peaking background	0.014	0.023	0.030	0.013
Detector Alignment	0.004	0.002	0.002	0.001
DCS decays	0.002	0.014	0.002	0.014
Potential Fit Bias	0.008	0.006	0.008	0.006
Other	0.002	0.006	0.004	0.003
Total	0.034	0.036	0.051	0.026

Results $D^{*+}D^-$



Fermilab, Oct. 7, 2008

$D^{*\pm}D^{\mp}$ time-integrated CP violating asymmetry

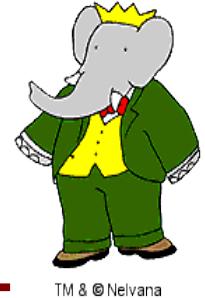


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$$\mathcal{A} = \frac{N_{D^{*+}D^-} - N_{D^+D^{*-}}}{N_{D^{*+}D^-} + N_{D^+D^{*-}}} = 0.008 \pm 0.048 \pm 0.013$$

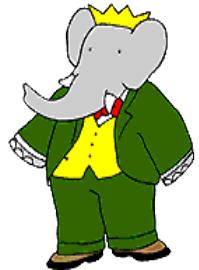
- Taken from the yields extracted with the full time dependent fit.
- Systematic error is entirely dominated by track reconstruction efficiency differences for positive and negative tracks.

Conclusion



- All parameters are consistent with those from $\sin 2\beta$ in $B^0 \rightarrow (c\bar{c})K^0$ decays.
- In contradiction with the Belle $B^0 \rightarrow D^+D^-$ results, we do not observe any direct CP violation.
- These are the best measurements to date of CP violation in these decay modes.
- All of the measurements are still statistically constrained and could benefit from a super flavor factory should it be built.
- With additional statistics, it would be possible to do a full time-dependent angular analysis of the $B^0 \rightarrow D^{*+}D^{*-}$ channel to measure the amplitudes, relative phases and $\cos 2\beta$.



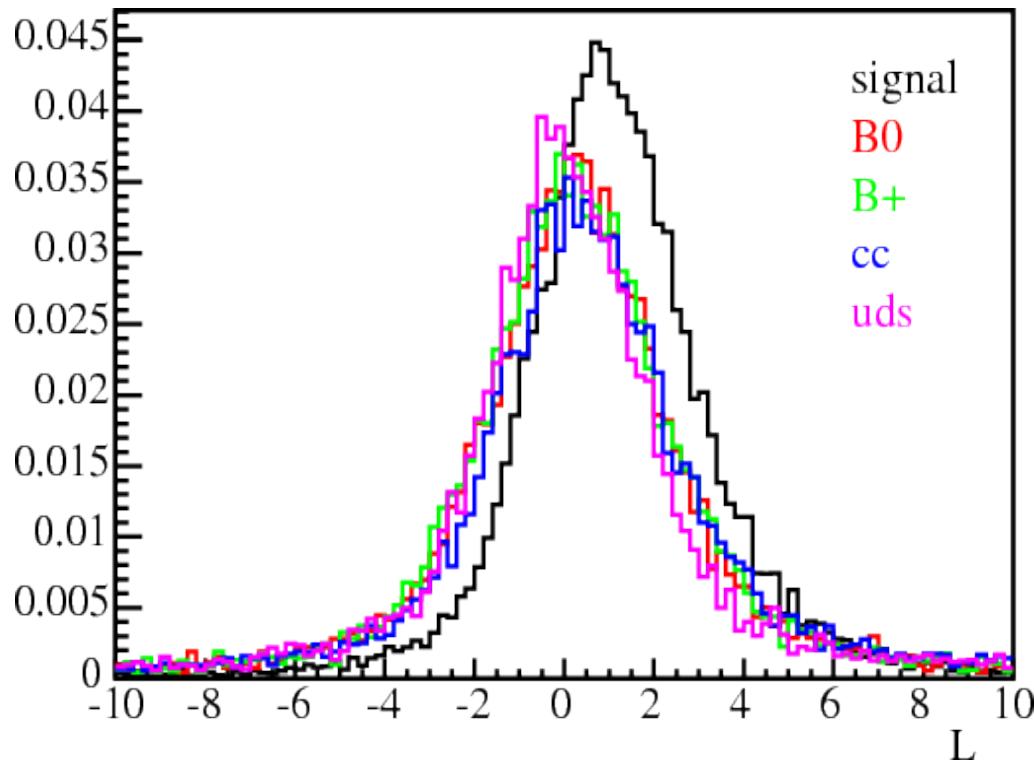
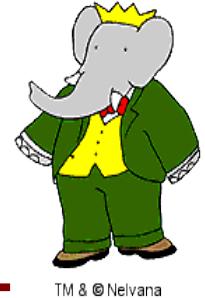


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Backup Slides

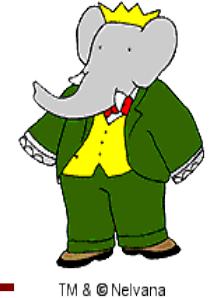


Selection Variables (Decay L)



$$\text{Decay } L = \frac{\ell_D + \ell_{\overline{D}}}{\sqrt{\sigma_{\ell_D}^2 + \sigma_{\ell_{\overline{D}}}^2}}$$

Background Δt distribution

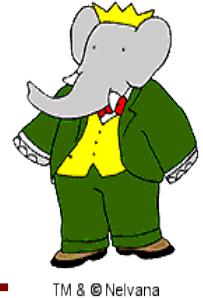


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- Lifetime and prompt components

$$\begin{aligned}\mathcal{F}_{\pm, \text{bg}}(\Delta t) \propto & \left[(1 - f_{\text{prompt}}) e^{-|\Delta t|/\tau_{eff}} \times \right. \\ & \{1 \pm S_{\text{bg}} \sin(\Delta m_d \Delta t) \pm C_{\text{bg}} \cos(\Delta m_d \Delta t)\} + \\ & \left. f_{\text{prompt}} \delta(\Delta t) \right] \otimes \mathcal{R}(\Delta t - \Delta t')\end{aligned}$$

Results $D^{*\pm}D^\mp$



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- Because $B^0 \rightarrow D^{*\pm}D^\mp$ are not a CP eigenstates, it is helpful to use a different parameterization. PRL 91 201802

$$S_{D^*D} = \frac{1}{2} (S_{D^{*+}D^-} + S_{D^+D^{*-}}) = -0.68 \pm 0.15 \pm 0.04$$

$$\Delta S_{D^*D} = \frac{1}{2} (S_{D^{*+}D^-} - S_{D^+D^{*-}}) = +0.05 \pm 0.15 \pm 0.02$$

$$C_{D^*D} = \frac{1}{2} (C_{D^{*+}D^-} + C_{D^+D^{*-}}) = +0.04 \pm 0.12 \pm 0.03$$

$$\Delta C_{D^*D} = \frac{1}{2} (C_{D^{*+}D^-} - C_{D^+D^{*-}}) = +0.04 \pm 0.12 \pm 0.03$$